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GUIDANCE FOR COURSE EVALUATION FORM

The Course Evaluation Form on the following page is very important to the continuing improvement and success of this course. The form is included in each Participant Workbook. During the course introduction, the Instructor will call the participants' attention to the form, its content, and the importance of its thoughtful completion at the end of the course. Participants will be encouraged to keep notes, or write down comments as the class progresses, in order to provide the best possible evaluation. The Instructor will direct participants to write down comments at the end of each day and to make use of the back of the form if more room is needed for comments.

On the last day of the course, just prior to the written examination, the Instructor will again refer to the form and instruct participants that completion of the form after their last examination is a requirement prior to leaving. Should the course have more than one Instructor, participants should be directed to list them as A, B, etc., with the Instructor's name beside the letter, and direct their answers in the Instructor Evaluation portion of the form accordingly.

UDOT
TRANSPORTATION TECHNICIAN QUALIFICATION PROGRAM
COURSE EVALUATION FORM

The UDOT Transportation Technician Qualification Program would appreciate your thoughtful completion of all items on this evaluation form. Your comments and constructive suggestions will be an asset in our continuing efforts to improve our course content and presentations.

Course Title: ____________________

Location: ____________________

Dates: ____________________

Your Name (Optional): ____________________

Employer: ____________________

Instructor(s) ____________________

COURSE CONTENT

Will the course help you perform your job better and with more understanding? Yes Maybe No

Explain: ____________________

____

Was there an adequate balance between theory and instruction? Yes Maybe No

Explain: ____________________

____

Did the course prepare you to confidently complete both examinations? Yes Maybe No

Explain: ____________________

____

What was the most beneficial aspect of the course? ____________________

____

What was the least beneficial aspect of the course? ____________________

____

GENERAL COMMENTS

General comments on the course, content, materials, presentation method, facility, registration process, etc. Include suggestions for additional Tips!

INSTRUCTOR EVALUATION

Were the objectives of the course, and the instructional and exam approach, clearly explained? Yes Maybe No

Explain:

Was the information presented in a clear, understandable manner? Yes Maybe No

Explain:

Did the instructors demonstrate a good knowledge of the subject? Yes Maybe No

Explain:

Did the instructors create an atmosphere in which to ask questions and hold open discussion? Yes Maybe No

Explain:

COURSE OBJECTIVES AND SCHEDULE

Learning Objectives

Instructional objectives for this course include:

- Becoming proficient in the following specifications, practices, and procedures:

  FOP for AASHTO M 323
  Standard Specification for Superpave Volumetric Mix Design

  FOP for AASHTO R 35
  Standard Practice for Superpave Volumetric Mix Design

  FOP for AASHTO R 30 and UDOT MOI 8-988
  Guidelines for Laboratory Mixing of Hot-Mix Asphalt (HMA) and Mixture Conditioning of HMA

  FOP for AASHTO T 312
  Standard Method for Preparing and Determining the Density of Hot-Mix Asphalt HMA) Specimens by Means of the Superpave Gyratory Compactor

  FOP for AASHTO T 283
  Resistance of Compacted Bituminous Mixtures to Moisture Induced Damage

  FOP for AASHTO T 324 and UDOT MOI 9-990
  Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)

  FOP for AASHTO M 325
  Standard Specification for Stone Matrix Asphalt (SMA)

  FOP for AASHTO R 46
  Standard Practice for Designing Stone Matrix Asphalt (SMA)

  FOP for AASHTO T 305
  Standard Method of Test for Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures

The overall goals of this course are to understand the basics of Superpave and SMA mix design, and to be competent with specific quality control test procedures identified for the Utah Department of Transportation (UDOT) Transportation Technician Qualification Program (TTQP).

It is assumed that the student has previously obtained a copy of the manual, and has adequately prepared for the qualification by studying and receiving training from a senior trainer.

Course Outline and Suggested Schedule

Day One

0900	Welcome Introduction of Instructors
0915	Presentations
1200	Lunch
1300	Presentations. Distribute copies of Sample Exams

Day Two

0800	Review Sample Exam and answer questions from the Previous Day
0900	Start of Written Exams
Varies	Practical Exams (After successful completion of written exam)

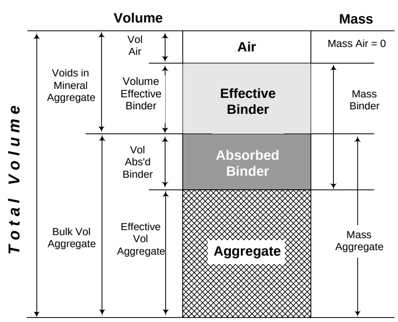
BASICS OF SUPERPAVE MIX DESIGNS

02

Introduction

Asphalt cement concrete (ACC) is a mixture of two primary ingredients: mineral aggregate and asphalt cement (AC) or binder as it is now termed. The binder holds the aggregate together in a moderately flexible rock-like mass. Hot mix asphalt (HMA) includes mixes that are produced at an elevated temperature. ACC and HMA are generally divided into three types of mixes, depending on the gradation of the aggregate: dense-graded, open-graded, and gap-graded.

Superpave HMA mixtures are a dense graded mix using high quality aggregates and binder used for the construction of surface courses on flexible pavements.



The binder is divided into two categories: absorbed (into the aggregate) and effective (which remains on the surface for binding aggregate particles together). Also, HMA contains air voids in addition to aggregate and binder.

Once the HMA mixture is mixed and compacted to optimum air void content (4%) it exhibits a certain level of stability that helps it withstand the combined action of environment and traffic loads. Several factors contribute to the level of stability offered by the HMA: the quality of aggregate and binder, and the gradation of the aggregate.

03

Five factors affect pavement performance:

1. Structural design
2. Mix design properties
3. Workmanship used to produce, place, and compact the mix
4. Loading factors
5. Environmental conditions.

This module presents information relating to item No. 2, Mix Design.

04 **Mix Design**

The objective of a mix design is to select the optimum binder content for a given aggregate source, binder source and optimum aggregate gradation. The FOP for AASHTO M 323 covers the Standard Specification for Superpave Volumetric Mix Designs.

The Superpave mix design and analysis system consists of three major components:

- Binder specification and selection
- Aggregate specification and evaluation
- Volumetric mix design and evaluation

The overall objective of the Superpave system is to specify the appropriate materials and mix design, and predict the performance of a given HMA pavement.

05 **Binder**

A binder specification is a process by which the designer can select and verify the appropriate grade of binder to be used on a specific project. To select a binder, it is important to understand how they behave.

06 **How Binders Behave**

The behavior of binders depends on:

- Temperature
- Time (duration) of Loading
- Age

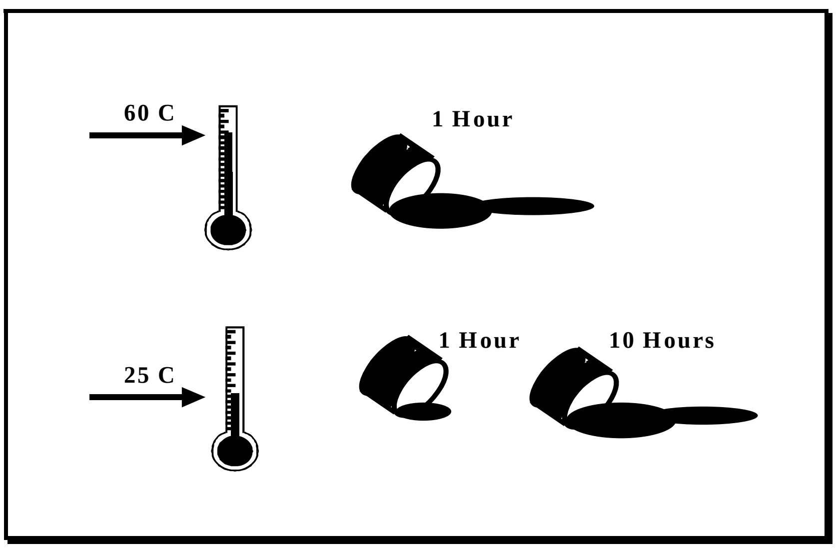
The first step in developing and understanding a binder grading system is to appreciate the behavior of the binder and the various factors that impact such behavior. Asphalt binders are viscoelastic materials whose behavior is dependent on temperature and time of loading. Because their chemical composition may change with time, their relative age in the road also impacts their engineering properties and, therefore, their behavior.

A unique property of a viscoelastic material is the superposition of temperature and time of loading, which means that the impact of temperature and time of loading on binders are interchangeable. Testing the binder at elevated temperatures can simulate behavior of a binder under a very slow loading rate.

Using such interrelationships, laboratory testing is used to simulate actual field conditions.

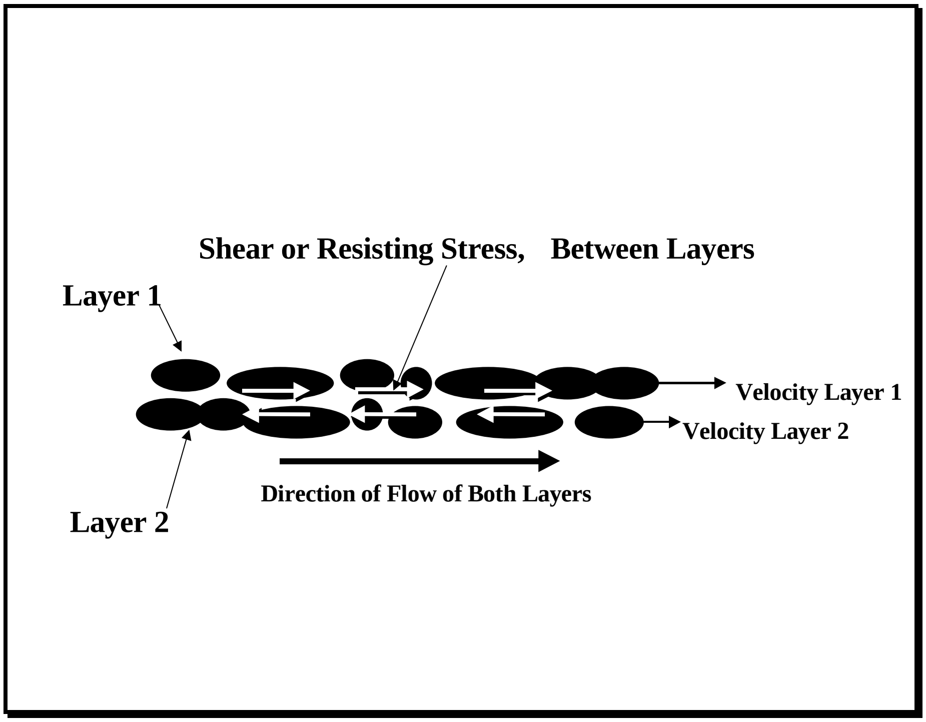
07 Temperature

The temperature that a binder is exposed to in the field depends on the location of the project. In high temperatures, such as those found in desert climates and during summer, the binder acts as a viscous liquid. At low temperatures, such as those found in cold climates and during winter, the binder acts as an elastic solid, which is more brittle. At intermediate temperatures the binder is viscoelastic, it has characteristics of both a viscous liquid and an elastic solid. Binders may be exposed to a range of extreme high temperatures to extreme low temperatures.



08

09 At elevated temperatures, when binders behave as viscous liquids, their resistance to shear deformations depends on the rate of shear stresses being applied. The resistance of binders to shear deformations is one important factor that controls the development of rutting in HMA mixtures.



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11

Time of Loading

The time (duration) of loading that a binder encounters in the field depends on the actual use of the pavement facility. Pavements on parking lots, tollbooths, and traffic lights are subjected to sustained loads. Pavements on highways and freeways are subjected to rapid loads.

The behavior of the binders changes from viscous liquids, as they are subjected to sustained loads, to elastic solids, as they are subjected to rapid loads. At facilities where traffic speed is intermediate, the binder behaves as a viscoelastic material.

- Sustained loads = Viscous liquid
- Rapid loads = Elastic solid
- Intermediate loads = Viscoelastic

12 **Aging Behavior**

Aging of binders is a process by which the binders become more brittle with time.

During construction the binder is subject to short-term aging due to hot mixing, placing, and compacting, which causes the volatiles to evaporate. In service the binder is subject to long-term aging because it reacts with oxygen, which results in oxidation or age hardening. Oxidation occurs more rapidly at elevated temperatures, a larger concern in hot, desert climates and hot summers.

13 **In-place performance**

The in-place life cycle of an HMA pavement depends on it's ability to resist:

- Permanent deformation (rutting)
- Fatigue cracking
- Thermal cracking

These factors are taken into consideration in the mixture design selection of binder and aggregate structure. Because binders are significantly impacted by temperature, time of loading and aging HMA pavements are also impacted by the same factors.

14 **Permanent Deformation (Rutting)**

The aggregate gradation is the most significant contributor to a mixtures ability to resist permanent deformation (rutting) although binder properties are significant.

15 **Fatigue Cracking**

Fatigue cracking in HMA pavements occurs as a long-term response to in-service conditions. The resistance of HMA pavements to fatigue cracking is generated through a complex interrelationship among binder, aggregate and pavement structure.

16 **Thermal Cracking**

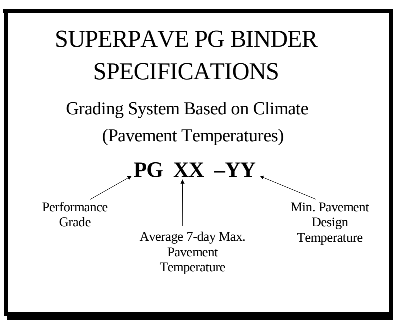
Thermal cracking of HMA pavements is mainly controlled by the properties of the binder. Thermal cracking is caused by excessive tensile stresses due to shrinkage.

The binder carries these tensile stresses; as the binder ages, it becomes more brittle and its ability to resist tensile stresses diminishes.

17 **Superpave PG Binder specification**

The Superpave PG binder specification, as outlined in AASHTO M 320, measures the physical properties of binders that can be directly related to field performance by engineering principles.

Because of the viscoelastic nature of the binder, rheological testing must be performed to fully describe its engineering properties. (Rheology is the study of the deformation and flow of matter.)



18 The final outcome of the Superpave binder grading system is to assign a performance-based grade for the binder. This grade indicates the range of in-
19 service temperatures of the binder to resist the various failure modes (rutting, fatigue and thermal cracking). The first number is the “high temperature grade,” and means the binder possesses adequate physical properties up to at least this temperature. The second number is the “low temperature grade,” and means the binder possesses adequate physical properties down to at least this temperature.

To identify the appropriate temperature range for the binder, its engineering properties must be evaluated at a temperature range that covers the expected temperatures during production, construction and service life.

As the binder is subjected to different levels of temperatures at various stages of its service life, its engineering (rheological) properties significantly change. Therefore, the critical properties that control the resistance of the binder to the various failure modes have to be evaluated at the appropriate combinations of temperature and aging conditions of the binder.

High/Intermediate Temperature Properties

20 The high/intermediate temperature properties are measured by:

- Rotational Viscometer (RV)
- Dynamic Shear Rheometer (DSR)
  - Original (not aged)
  - Short-term aged = RTFO (Rolling Thin Film Oven)
  - Long-term aged = PAV (Pressure Aging Vessel)

Low Temperature Properties

21 The low temperature properties are measured by:

- Bending Beam Rheometer (BBR) at RTFO and PAV
- Direct Tension Tester (DTT) at RTFO and PAV
  - Short-term aged = RTFO (Rolling Thin Film Oven)
  - Long-term aged = PAV (Pressure Aging Vessel)

22 Binder selection

The selection of the binder depends on the climatic condition of the project site:

- Low temperature
  - Lowest pavement temperature (not air temperature)
- High temperature
  - Average 7-day maximum pavement temperature (not air temperature)

The selection of the binder also makes some adjustments for the anticipated traffic speed.

Aggregate Specification and Evaluation

23 Consensus Properties

The aggregate specifications include consensus properties determined by the following test procedures:

- Coarse aggregate angularity (ASTM D 5821)
- Fine aggregate angularity (AASHTO T 304)
- Flat and elongated particles (ASTM D 4791)
- Clay content (AASHTO T 176)

Because aggregates make up approximately 95 percent of the HMA mix, their properties are critical to the performance of the mix. The Superpave mix design system specifies critical properties for the fine and coarse portions of the aggregates. Fine aggregates are defined as passing the #4 sieve. Coarse aggregates are defined as retained on the #4 sieve.

The gradation of the aggregates controls the long-term performance of the HMA mix. The concept of the gradation specification is that a dense graded mix, which does not experience tenderness during the construction process, should provide good performance.

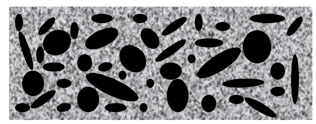
A large portion of the Superpave aggregate specification deals with the physical shape of the aggregate because it significantly impacts the interlocking and adhesion properties of the aggregates.

The rutting resistance of the HMA mixture is highly dependent on the interlocking of the aggregate particles. Rounded and smooth aggregates slip relative to each other when subjected to loads. Therefore, the resistance of HMA mixtures to shear deformations is increased when large percentages of cubical and rough-textured aggregates are used.

The design aggregate structure approach ensures that the aggregate will develop a strong stone skeleton to enhance resistance to rutting, while allowing for sufficient void spaces to enhance mixture durability.

Contrasting Stone

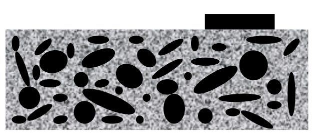
Cubical Aggregate



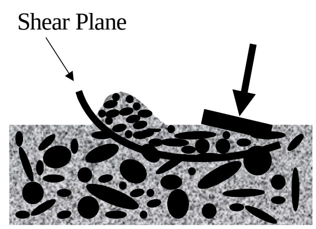
Rounded Aggregate

24

Shearing Behavior of Aggregate



Before Load



After Load

25

26 **Gradation Controls**

- Nominal Maximum Size
- 0.45 power chart
- Control points

27 **Aggregate Source Properties**

The Superpave aggregate specifications also recognize properties that are controlled by the aggregate source:

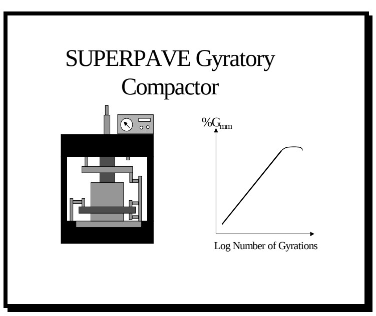
- L. A Abrasion (AASHTO T 96)
- Soundness (AASHTO T 104)
- Clay lumps and friable particles (AASHTO T 112)

These aggregate specifications include properties that are considered to be critical to the overall quality of the aggregate particle. It is up to the highway agency to set the limits that have worked well under local conditions.

28 **Mix Design Overview**

The Superpave system includes:

- **Volumetric Mix Design**
- Performance based tests
- Performance prediction



This module is concerned with the Volumetric Mix Design.

29 The **Volumetric Mix Design** includes:

- Materials Selection (Aggregate & Binder)
- Gradation Selection (Trial Series)
- 30 Optimum Binder Content Selection

31 **Definition of Terms**

- G_{mm} = theoretical maximum specific gravity
- G_{mb} = measured bulk specific gravity
- G_{sb}(OD) = oven-dry bulk specific gravity of aggregate
- G_{sa} = apparent specific gravity of aggregate
- G_{se} = effective specific gravity of aggregate
- 32 G_b = specific gravity of the binder

- V_a = air voids
- VMA = voids in mineral aggregate
- VFA = voids filled with asphalt binder
- V_{ba} = absorbed binder volume
- V_{be} = effective binder volume
- P_b = percent binder content
- P_{ba} = percent absorbed binder
33 • P_{be} = percent effective binder content
- P_s = percent of aggregate
- $P_{.075}/P_{be}$ = dust to effective binder ratio
- RAP = Reclaimed Asphalt Pavement
- Nominal Maximum Aggregate Size:
  One sieve size larger than the first sieve to cumulatively retain more than 10%
- Maximum Aggregate Size:
  One sieve size larger than the nominal maximum aggregate size

34 • Design ESALs:
  Design equivalent 18,000 lb (80kN) single axle load. For mixed traffic levels standard load equivalent factors are used.

  Design ESALs are the anticipated project traffic level expected over a 20-year period. ESALs should be calculated for a 20-year design life.

35 **Prerequisite Tests**

- AASHTO T 2 Sampling of Aggregates
- AASHTO T 248 Reducing Samples of Aggregate to Testing
- AASHTO T 11 Materials Finer than No. 200 Sieve in Mineral Aggregate by Washing
- AASHTO T 27 Sieve Analysis of Fine and Coarse Aggregates
- AASHTO T 84 and T 85 Specific Gravity of Fine and Coarse Aggregates

36 Optimum Aggregate Gradation Selection (General)

1. Establish three trial aggregate gradations that meet all aggregate requirements.
2. Determine initial binder content for each trial aggregate gradation.
3. Compact two samples for each trial aggregate gradation at the initial binder content.
4. 37 Measure volumetric properties of the compacted samples.
5. Estimate volumetric properties at V_a= 4.0%.
6. Select the aggregate gradation that best satisfies the design criteria.

38 Select Optimum Binder Content (General)

1. Prepare and compact replicate samples of the design gradation at four levels of binder content. (Est. design, 0.5% below, 0.5% above and 1.0% above)
2. Measure volumetric properties of the compacted samples.
3. Determine the optimum asphalt binder content.
4. 39 Check the volumetric properties at the optimum binder content against the design criteria.
5. Check design criteria at N_{max} (replicate specimens).
6. Check moisture susceptibility of the mixture at the recommended P_b (AASHTO T 283).

BASICS OF STONE MATRIX ASPHALT (SMA) MIX DESIGNS

Stone Matrix Asphalt
Aggregate Structure

41

Superpave
Aggregate Structure

40

Introduction

SMA is a gap-graded mixture having a concentration of coarse aggregate particles resulting in “stone-on-stone” contact. The aggregate is combined with a rich asphalt binder mortar consisting of binder, mineral filler, and stabilizing additive. The combination of proper aggregate structure and binder mortar allows design of mixtures based on volumetric properties with “normal” air void content (approximately 4.0 percent) that, when properly produced and placed, can result in greater durability and resistance to rutting.

42 SMA was developed in Europe as a response to the critical need for pavements that were resistant to abrasion from the use of studded tires, and various pavement distresses induced by heavy traffic. SMA proved very successful in Germany, and its use continued even after elimination of studded tires.

SMA was initially adopted from the Germans by Sweden and Denmark, but is now used extensively in Norway, Finland, Austria, France, Switzerland, and the Netherlands.

The National Asphalt Pavement Association (NAPA) was introduced to the mix during a European asphalt study tour in 1990, after which the U.S. began experimenting with SMA mixtures. Since then, SMA use has increased in the U.S.A.

43 FOP’s for the Standard Specification for SMA (AASHTO M 325) and the Standard Practice for Designing SMA (AASHTO R 46) are contained in this manual.

44 ## Basics of SMA

Superpave Gyratory Compactor (SGC)

The Superpave Gyratory Compactor (SGC) is the
method used for preparing compacted specimens
during SMA mix design. Mixtures are normally
compacted using 100 gyrations (75 gyrations are
used when the coarse aggregate has L.A. Abrasion
45 loss exceeding 30 percent).

As stated in the introduction, SMA is a gap-graded mixture. This means that the intermediate size fractions, present in dense-graded materials, are largely missing in SMA.

46 During design, SMA mixtures are evaluated for compliance with certain specified volumetric properties including voids in the mineral aggregate (VMA), air voids (V_a), as well as voids in the coarse aggregate fraction of the combined grading (VCA). VCA is expressed in two ways:

1. VCA_{DRC} describes VCA in the dry-rodded condition when tested according to AASHTO T 19.
2. VCA_{MIX} describes VCA in the compacted mixture.

Compliance of the mixture with AASHTO M 325 requires that VCA_{MIX} be less than VCA_{DRC}. (Calculation methods for VCA_{DRC} and VCA_{MIX} are contained in the FOP for AASHTO R 46).

The SMA specification for mixture properties requires relatively high values for minimum VMA and binder content, while maintaining V_a of approximately 4.0 percent. This results in SMA mixtures having binder contents significantly higher than those of dense-graded mixtures such as Superpave.

“Fat” spots due to draindown

47 Binder content is required to be at least 6.0 percent
and may be higher, depending on grading and
aggregate specific gravity. This results in greater
48 potential for draindown (migration of binder away
from aggregate particles). For this reason,
stabilizers such as cellulose and mineral fibers are
added to the binder to prevent excessive draindown
characteristics.

The mixture is tested during the design phase, and during production, according to AASHTO T 305 to assess draindown potential and compliance with the specification.

49 The mixture must also be evaluated for damage due to moisture susceptibility according to the FOP for AASHTO T 283. This test is conducted on specimens compacted according to the FOP for AASHTO T 312 at an air void content of approximately 6 percent.

50 Binder Requirements

Binders used in SMA mix design must comply with AASHTO M 320. Reference is also made to AASHTO M 323 for binder adjustments specific to project climate conditions and traffic loading.

51 Aggregate Requirements

The SMA aggregate specification requires use of materials that are 100 percent crushed, meeting properties based on the results of certain specified test methods.

Coarse aggregate quality requirements are based on tests for Los Angeles Abrasion, Flat and Elongated Particles, Absorption, Soundness, and Crushed Content (Fractured Face). Fine aggregate quality requirements are based on tests for Soundness, Liquid Limit, and Plasticity Index.

Mineral filler specifications require use of finely divided mineral matter, such as crusher fines and fly ash, that are free from organic impurities and that have a plasticity index not greater than four.

AASHTO M 325 provides combined grading bands for three nominal maximum aggregate sizes: 3/4" (19 mm), 1/2" (12.5 mm), and 3/8” (9.5 mm). Coarse aggregate is defined as material retained on the No. 4 sieve for the 3/4" and 1/2" nominal maximum aggregate sizes, and as material retained on the No. 8 sieve for the 3/8” nominal maximum size.

When the oven-dry bulk specific gravity of the different materials used in the mixture vary by more than 0.2, combined grading must be calculated based on volumetric percentage.

52 Mixture Property Requirements

Final mixture property requirements may be summarized as follows:

- Air Void Content: Generally 4.0 percent, but not less than 3.0 percent for low traffic levels or colder climates.
- VMA: 17.0 percent minimum
- VCA_{MIX}: Lower than VCA_{DRC}
- TSR: 0.80 minimum
- Draindown: 0.3 percent maximum
- Binder Content: 6.0 percent minimum. Some adjustment is allowed for aggregates of high specific gravity.

53 Mix Design Overview

SMA mix design includes the following:

- Materials Selection (Aggregates, Binder, Mineral Filler, Stabilizing Additive)
- Gradation Selection (Trial Series)
- Optimum Binder Content Selection

54 Definition of Terms

- **Air Voids (V_a)**
  The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture.
- **G_{CA}**
  Oven-dry bulk specific gravity of the coarse aggregate fraction of the combined grading.

55
- **P_{CA}**
  Percent of coarse aggregate in the combined grading.
- **SMA Mortar**
  A mixture of asphalt binder, filler (material passing the No. 200 sieve), and stabilizing additive.

SMA Surface

- **Stabilizing Additive**
  Either cellulose or mineral fiber.

56 - **Stone Matrix Asphalt (SMA)**
  A Hot-Mix Asphalt (HMA) mixture consisting of a coarse aggregate skeleton
  57 with stone-on-stone contact, and a rich asphalt binder mortar.

58 - **Stone-on-Stone Contact**
  The point where the VCA of the compacted mixture is less than the VCA of the dry-rodded coarse aggregate.

59 - **VCA**
  Volume of voids between coarse aggregate particles in the combined grading.

- **VCA_{DRC}**
  Volume of voids between coarse aggregate particles in the combined gradation (dry-rodded condition).

- **VCA_{MIX}**
  Volume of voids between coarse aggregate particles of the compacted mixture (air voids, binder, fine aggregate, mineral filler, and stabilizing additive).

60 ## Prerequisite Tests

- **AASHTO T 2 –** Sampling of Aggregates
- **AASHTO T 248 –** Reducing Samples of Aggregate to Testing Size
- **AASHTO T 11 –** Materials Finer than No. 200 Sieve in Mineral Aggregate by Washing
- **AASHTO T 27 –** Sieve Analysis of Fine and Coarse Aggregates
- **AASHTO T 84 and T 85 –** Specific Gravity and Absorption of Fine and Coarse Aggregates

61 - **AASHTO T 19 –** Bulk Density (“Unit Weight”) and Voids in Aggregate
- **AASHTO T 89 and T 90 –** Liquid Limit, Plastic Limit and Plasticity Index
- **AASHTO T 96 –** Los Angeles Abrasion of Coarse Aggregate

- **AASHTO T 104 –** Soundness of Coarse and Fine Aggregates

62

- **ASTM D 4791 –** Flat Particles, Elongated Particles, or Flat & Elongated Particles in Coarse Aggregate
- **ASTM D 5821 –** Determining the Percentage of Fractured Particles in Coarse Aggregate

63

Optimum Gradation Selection (General)

1. Perform prerequisite procedures / tests.
2. Establish at least three trial blend gradings (either from experience, or one each along coarse and fine limits and the center of the grading band).
3. Establish trial binder content. AASHTO R 46 recommends binder content from 6.0 to 6.5 percent when previous experience is not available.
4. Mix and compact trial blend specimens according to the FOP's for AASHTO R 30 and T 312.
5. Evaluate compacted trial mixtures.
6. Select optimum aggregate grading (lowest coarse aggregate content where the mixture meets the minimum VMA, and VCA_{MIX} is lower than VCA_{DRC}).

64

Select Optimum Binder Content (General)

Using the optimum grading, the steps for selecting the optimum binder content are:

1. Select Binder Contents (minimum of three binder contents that will encompass required air void content).
2. Fabricate and Compact Specimens (using FOP's for AASHTO R 30 and T 312).
3. Select Optimum Binder Content (binder content at which the mixture meets air void and minimum VMA requirements, and where VCA_{MIX} is lower than VCA_{DRC}).
4. Evaluate TSR at optimum binder content (compact at 6 percent air voids according to T 312, test according to T 283).
5. Evaluate Draindown at optimum binder content (T 305).

M 323

STANDARD SPECIFICATION FOR SUPERPAVE VOLUMETRIC MIX DESIGN FOP FOR AASHTO M 323

M 323

STANDARD SPECIFICATION FOR SUPERPAVE VOLUMETRIC MIX DESIGN FOP FOR AASHTO M 323

STANDARD SPECIFICATION FOR SUPERPAVE VOLUMETRIC MIX DESIGN FOP FOR AASHTO M 323

Significance

The Superpave volumetric mix design process uses combinations of aggregates and binders to produce hot-mix asphalt (HMA) job-mix formulas conforming to specified requirements.

02 Scope

This standard specifies minimum quality requirements governing binder and aggregate selection, and establishes specifications for volumetric properties of Superpave mix designs.

03 Binder Requirements

The binder shall meet the following:

- Performance-graded
- Meet requirements of AASHTO M 320
- Appropriate for climate
- Appropriate for traffic loading
- Or as specified by the contract documents

The grading system is illustrated by the following graphic:

04

SUPERPAVE PG BINDER SPECIFICATIONS

- Grading System Based on Climate (Pavement Temperatures)

PG XX –YY

Performance Grade

Average 7-day Max Pavement Temperature

Min Pavement Design Temperature

05

Binder Adjustments

Traffic Speed and Traffic Level

If traffic speed or design ESALs warrant, the high-temperature grade should be increased by the number of grade equivalents in Table 1.

06

Table 1
Adjustment to the High Temperature Grade of the Binder[1]
Based on Traffic Speed and Traffic Level

Design ESALs[2] (Million)	Traffic Load Rate		
	Standing[3]	Slow[4]	Standard[5]
< 0.3	--	--	--
0.3 to < 3	2	1	--
3 to < 10	2	1	--
10 to < 30	2	1	--[6]
≥ 30	2	1	1

[1] Increase the high-temperature grade by the number of grade equivalents indicated (one grade is equivalent to 6° C).

[2] The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

[3] *Standing Traffic* – where the average speed is less than 20 km/h (12 mph).

[4] *Slow Traffic* – where the average speed ranges from 20 to 70 km/h (12 to 43 mph).

[5] *Standard Traffic* – where the average traffic speed is greater than 70 km/h (43 mph).

[6] Consideration should be given to increasing the high-temperature grade by one grade equivalent.

RAP Usage

If RAP (Reclaimed Asphalt Pavement) is to be used, adjust the binder grade according to Table 2 to account for RAP binder stiffness and amount. For procedures for developing a blending chart refer to AASHTO M 323, Appendix X1.

Table 2 07
Binder Adjustment for RAP Usage

Recommended Virgin Asphalt Binder Grade	RAP Percentage
No change in binder selection	<15
Select virgin binder one grade softer than normal (e.g., select a PG 58 –28 if a PG 64 –22 would normally be used)	15-25
Follow recommendations from blending charts (see Appendix X1 of AASHTO M 323)	>25

Combined Aggregate Requirements

08 **Size requirements:**

- HMA surface course:
  Nominal maximum size: #4 to 3/4 inch
- HMA subsurface courses:
  Nominal maximum size: 1½ inch maximum.

Gradation control points:

- When tested according to AASHTO T 11 and AASHTO T 27, the combined aggregate gradation shall conform to the gradation control points in Table 3.

Table 3
Gradation Control Points 09

Sieve Size	**Nominal Maximum Aggregate Size (% Passing)**											
	1½”		1”		3/4”		1/2”		3/8”		#4	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
2”	100	-	-	-	-	-	-	-	-	-	-	-
1½”	90	100	100	-	-	-	-	-	-	-	-	-
1”	-	90	90	100	100	-	-	-	-	-	-	-
3/4"	-	-	-	90	90	100	100	-	-	-	-	-
1/2"	-	-	-	-	-	90	90	100	100	-	100	-
3/8”	-	-	-	-	-	-	-	90	90	100	95	100
#4	-	-	-	-	-	-	-	-	-	90	90	100
#8	15	41	19	45	23	49	28	58	32	67	-	-
#16	-	-	-	-	-	-	-	-	-	-	30	60
#200	0	6	1	7	2	8	2	10	2	10	6	12

Gradation Classification:

- The combined aggregate gradation is classified as coarse graded when it passes below the Primary Control Sieve (PCS) control point. All other gradations are classified as fine. See Table 4.

Table 4
Gradation Classification 10

PCS Control Point for Mixture Nominal Maximum Aggregate Size (% Passing)					
Nominal Maximum Aggregate Size	**1½”**	**1”**	**3/4"**	**1/2"**	**3/8”**
Primary Control Sieve	3/8”	#4	4	#8	#8
PCS Control Point (% Passing)	47	40	47	39	47

Aggregate Consensus Property Requirements:

- Coarse Aggregate Angularity shall be measured according to ASTM D 5821 (Determining the Percentage of Fractured Particles in Coarse Aggregate).
- Fine Aggregate Angularity (Uncompacted Void Content) shall be measured according to AASHTO T 304 Method A.

- Sand Equivalent shall be measured according to AASHTO T 176.
- Flat-and-Elongated shall be measured according to ASTM D 4791 except the material passing the 3/8 inch and retained on the #4 will be included. The ratio of 5:1, length to thickness, will be used. (Some states may require a different ratio.)

Aggregate Consensus Properties of aggregate blends used for Super Pave Mixture Designs shall meet the requirements listed in Table 5.

Table 5
Superpave Aggregate Consensus Property Requirements 11

Design[1] ESALs (million)	Fractured Face Coarse Aggregate (Percent) Minimum		Uncompacted Void Content, Fine Aggregate (Percent) Minimum		Sand Equivalent (Percent) Minimum	Flat and Elongated[3] (Percent) Maximum
	Depth from Surface[4]		Depth from Surface[4]			
	≤ 4”	> 4”	≤ 4”	> 4”		
< 0.3	55/-	-/-	-	-	40	-
0.3 to < 3	75/-	50/-	40	40	40	10
3 to < 10	85/80[2]	60/-	45	40	45	
10 to < 30	95/90	80/75	45	40	45	
≥ 30	100/100	100/100	45	45	50	

(1) The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.
(2) 85/80 denotes that 85 percent of the coarse aggregate has one fractured face and 80 percent have two or more fractured faces.
(3) This criteria does not apply to the #4 nominal maximum size mixtures.
(4) If less than 25% of a lift is within 4 inch of the surface, the lift may be considered to be below 4 inch.

When RAP is used the aggregate shall be extracted (using solvent or ignition oven) from the RAP according to Agency specifications. This aggregate shall be used in determining the combined aggregate gradation and conformance to the aggregate consensus properties, with the exception of sand equivalent. The sand equivalent shall apply to the aggregate blend prior to RAP aggregate inclusion.

HMA Design Requirements

When compacted in accordance with the FOP for AASHTO T 312, the mix design shall meet the design requirements in Table 6. (See the FOP for

AASHTO R 35 for N_{ini}, N_{des}, & N_{max} number of gyrations.)

12 When tested in accordance with the FOP for AASHTO T 283, the HMA design shall have a minimum tensile strength ratio of 0.80 when compacted in accordance with the FOP for AASHTO T 312 at 7.0 ±0.5 percent air voids.

Table 6 13
Superpave HMA Design Requirements

<table>
<tr><th rowspan="3">Design Esals[1] (million)</th><th colspan="3">Required Relative Density (% of Theoretical Maximum Specific Gravity)</th><th colspan="6">Voids in Mineral Aggregate[7] Percent Minimum</th><th rowspan="3">% Voids Filled with Asphalt (VFA) Range[2]</th><th rowspan="3">Dust-to-Binder Ratio Range[3]</th></tr>
<tr><th rowspan="2">$N_{initial}$</th><th rowspan="2">N_{design}</th><th rowspan="2">N_{max}</th><th colspan="6">Nominal Maximum Aggregate Size</th></tr>
<tr><th>1½”</th><th>1”</th><th>¾”</th><th>½”</th><th>⅜”</th><th>#4</th></tr>
<tr><td><0.3</td><td>≤91.5</td><td rowspan="5">96.0[6]</td><td rowspan="5">≤98.0</td><td rowspan="5">11.0</td><td rowspan="5">12.0</td><td rowspan="5">13.0</td><td rowspan="5">14.0</td><td rowspan="5">15.0</td><td rowspan="5">16.0</td><td>70-80[4]</td><td rowspan="5">0.6-1.2</td></tr>
<tr><td>0.3 to <3</td><td>≤90.5</td><td>65-78</td></tr>
<tr><td>3 to <10</td><td rowspan="3">≤89.0</td><td rowspan="3">65-75[5]</td></tr>
<tr><td>10 to <30</td></tr>
<tr><td>≥30</td></tr>
</table>

(1) The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.
(2) For 1½ inch nominal maximum size mixtures, the specified lower limit of the VFA range is 64% for all traffic levels.
(3) For #4 nominal maximum size mixtures, the dust-to-binder ratio shall be 0.9 to 2.0.
(4) For 1 inch nominal maximum size mixtures, the specified lower limit of the VFA shall be 67 percent for design traffic levels < 0.3 million ESALs.
(5) For design traffic levels >3 million ESALs, 3/8” nominal maximum size mixtures, the specified VFA range shall be 73 to 76 percent and for #4 nominal maximum size mixtures shall be 75 to 78 percent.
(6) Corresponds to an Air Void Content (V_a) of 4.0%.
(7) VMA greater than 2% above the minimum should be avoided.

13

Note: If the aggregate gradation passes beneath the PCS Control Point specified in Table 4, the dust-to-binder ratio may be increased to 0.8–1.6 at the agencies discretion.

REVIEW QUESTIONS

1. With what specification must the binder comply? What does PG 64 –34 mean?

2. When using RAP in a mix design, how might the selection of the virgin binder be different than if no RAP is used?

3. Describe the aggregate size requirements for surface courses, for subsurface courses.

4. What are the specified gradation controls?

5. Name the aggregate consensus properties.

6. Is RAP aggregate used for determining all of the consensus properties? If not, for which test(s) would the RAP aggregate be excluded?

7. For design ESAL's of 6 million, what %G_{mm} at N_{ini} is the maximum allowed?

8. For design ESAL's of 7 million, what is the lower limit of VFA range for a 3/8 inch nominal maximum size aggregate?

R 35

STANDARD PRACTICE FOR SUPERPAVE VOLUMETRIC MIX DESIGN
FOP FOR AASHTO R 35

R 35

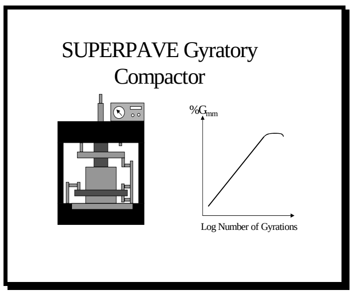
STANDARD PRACTICE FOR SUPERPAVE VOLUMETRIC MIX DESIGN

FOP FOR AASHTO R 35

STANDARD PRACTICE FOR SUPERPAVE VOLUMETRIC MIX DESIGN FOP FOR AASHTO R 35

Significance

This FOP for Superpave volumetric mix design uses aggregate and mixture properties to produce a hot-mix asphalt (HMA) job-mix formula based on the volumetric properties in terms of air voids (V_a), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA).



02

Scope

Superpave design and analysis includes:

- Volumetric mix design
- Performance based tests
- Performance prediction

This FOP provides the basic steps needed to produce an HMA mixture that meets the Superpave HMA volumetric mix design requirements.

The Superpave gyratory compactor is the method of compaction for laboratory and field control testing and evaluation of the HMA mixtures.

03

Mix Design Overview

The major steps that must be conducted for the successful completion of the Superpave mix design process are:

- Evaluating trial gradations
- Selection of optimum binder content

04

Prerequisite Tests

- AASHTO T 2 Sampling of Aggregates
- AASHTO T 248 Reducing Samples of Aggregate to Testing Size
- AASHTO T 11 Materials Finer than 75µm (No. 200) Sieve in Mineral Aggregate by Washing
- AASHTO T 27 Sieve Analysis of Fine and Coarse Aggregates
- AASHTO T 84 and T 85 Specific Gravity of

Fine and Coarse Aggregates

05 Definition of Terms

- G_{mm} = theoretical maximum specific gravity
- G_{mb} = measured bulk specific gravity
- G_{sb}(OD) = oven-dry bulk specific gravity of aggregate
- G_{sa} = apparent specific gravity of aggregate
- G_{se} = effective specific gravity of aggregate
- G_b = specific gravity of the binder
- 06 V_a = air voids
- VMA = voids in mineral aggregate
- VFA = voids filled with asphalt (binder)
- V_{ba} = absorbed binder volume
- V_{be} = effective binder volume
- P_b = percent binder content
- P_{ba} = percent absorbed binder
- P_{be} = percent effective binder content
- P_s = percent of aggregate
- 07 $P_{0.075}/P_{be}$ = dust to effective binder ratio
- RAP = Reclaimed Asphalt Pavement
- Nominal Maximum Aggregate Size:
  One sieve size larger than the first sieve to cumulatively retain more than 10%
- Maximum Aggregate Size:
  One sieve size larger than the nominal maximum aggregate size
- 08 Design ESALs:
  Design equivalent 18,000 lb (80kN) single axle load

  Note: Design ESALs are the anticipated project traffic level expected over a 20-year period. For pavements designed for more or less than 20 years ESALs should be calculated for a 20-year design life.

09 Selecting Design Aggregate Structure

1. Establish trial blends
2. Establish initial trial binder content
3. Compact trial blend specimens
4. Evaluate compacted trial mixtures
5. Select the best design aggregate structure

10

Establish Trial Blends

Specifications for aggregate gradation are usually given as upper and lower limits on certain sieve sizes. Within these upper and lower limits, numerous aggregate gradations can be fabricated.

Any Combined Gradation which meets AASHTO M 323 gradation controls is acceptable as a trial blend (see Table 3 of FOP for AASHTO M 323).

- Select a minimum of 3 blends for design work
- Check all three blends against aggregate specifications

11

Preparing Aggregate Blend Gradations

1. Select binder in accordance with AASHTO M 320
    - Obtain specific gravity of binder (G_b) (AASHTO T 228)
2. Obtain samples of aggregate from proposed stockpiles and reduce to testing size (AASHTO T 2 & T 248)
3. Wash and grade the samples (AASHTO T 11/T 27)
4. Determine bulk and apparent specific gravities, G_{sb}(OD) & G_{sa}, for each fine and coarse aggregate portion (AASHTO T 84 and T 85)
5. Obtain the specific gravity of mineral filler (AASHTO T 100)

Using the following equation, determine the combined aggregate gradation of each blend:

$$P = Aa + Bb + Cc + \ldots\ldots Nn$$

Where:

P	=	percent passing for combined aggregates
A, B, C…N	=	Percent passing for aggregates A, B, C, etc. expressed as percentages
a, b, c …n	=	Percentage of aggregates A, B, C used, expressed as a decimal, totaling 1.00

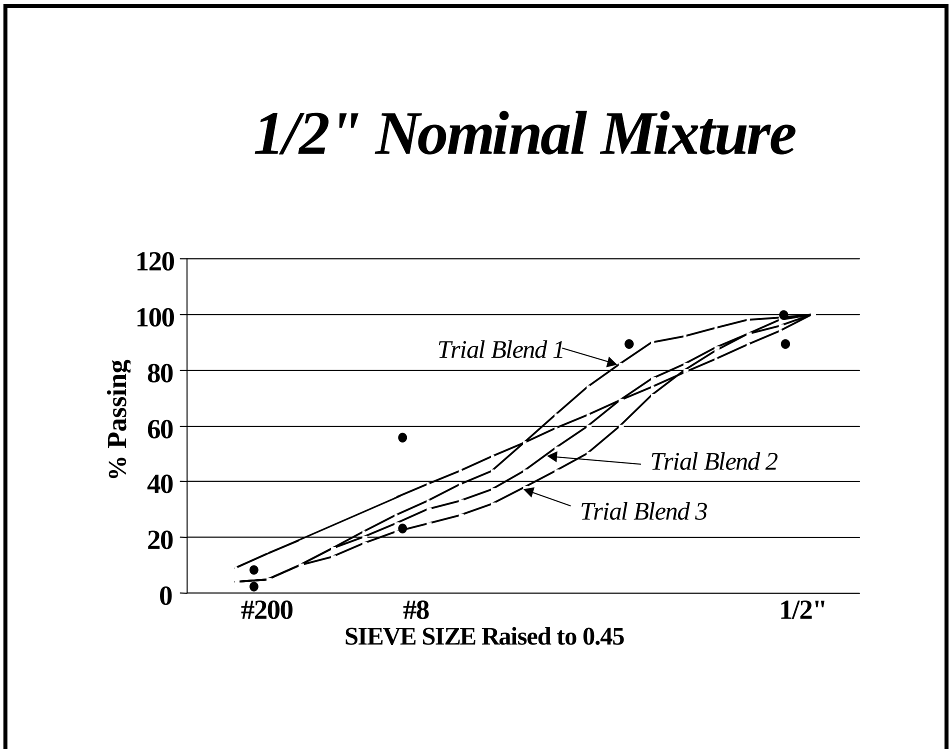
Calculate absorption of the combined aggregate using the above formula, replacing individual aggregate absorptions for the values of A, B, C, …N.

The three trial aggregate blend gradations are plotted on a 0.45-power gradation analysis chart. Confirm that each trial blend meets Tables 3 and 4 of the FOP for AASHTO M 323.

Figure 1 is an example of a gradation plot of three acceptable trial blends.

Figure 1

12



13

Check Blends for Compliance

Conduct quality tests on each trial blend to confirm they meet minimum quality requirements specified in Table 5 of the FOP for AASHTO M 323.

- Coarse Aggregate Angularity (ASTM D 5821)
- Fine Aggregate Angularity (AASHTO T 304)
- Sand Equivalent (AASHTO T 176)
- Flat and elongated particles (ASTM D4791)

NOTE: The designer may elect to perform quality tests on each stockpile and estimate the combined results.

Table 1 – Aggregate Blending Worksheet

Product Identification	Percentage of Products Used (Decimal)				
	Blend No. 1	**a** (1/2")	**b** (3/8")	**c** (1/4")	**d** (Fine)
A (1/2")	**0.20**	0.20			
B (3/8")	**0.28**		0.28		
C (1/4")	**0.12**			0.12	
D (Fine)	**0.40**				0.40
Total	**1.00**	0.20	0.28	0.12	0.40

Grading for 1/2" (12.5 mm) Mix

Sieve Size	**Comb.**	Individual Product Contributions			
1"	**100**	20.0	28.0	12.0	40.0
3/4"	**100**	20.0	28.0	12.0	40.0
1/2"	**98**	18.2	28.0	12.0	40.0
3/8"	**81**	2.4	26.9	12.0	40.0
No. 4	**55**	0.4	5.6	9.0	40.0
No. 8	**45**	0.4	4.2	2.5	38.0
No. 16	**34**	0.4	1.4	1.2	31.2
No. 30	**20**	0.2	0.6	0.6	18.4
No. 50	**11**	0.2	0.6	0.4	10.0
No. 100	**8**	0.2	0.6	0.4	7.2
No. 200	**4.8**	0.1	0.4	0.2	4.1

Individual Product Identification and Gradations (Percent Passing)

Sieve Size	**A** (1/2")	**B** (3/8")	**C** (1/4")	**D** (Fine)
1"	100	100	100	100
3/4"	100	100	100	100
1/2"	91	100	100	100
3/8"	12	96	100	100
No. 4	2	20	75	100
No. 8	2	15	21	95
No. 16	2	5	10	78
No. 30	1	2	5	46
No. 50	1	2	3	25
No. 100	1	2	3	18
No. 200	0.3	1.5	2.0	10.3

Combined Specific Gravity and Absorption Data

G_{sb} (OD)	**2.623**	0.525	0.734	0.315	1.049
G_{sb} (SSD)	**2.643**	0.529	0.740	0.317	1.057
G_{sa}	**2.677**	0.535	0.750	0.321	1.071
Absorption	**0.684**	0.080	0.126	0.118	0.360

Individual Aggregate Specific Gravity and Absorption Data

G_{sb} (OD)	2.643	2.641	2.589	2.610
G_{sb} (SSD)	2.655	2.654	2.626	2.635
G_{sa}	2.673	2.676	2.689	2.677
Absorption	0.40	0.45	0.98	0.90

Additional Design Information for Calculation of P_{bi}	
Binder Specific Gravity G_b	1.022
Log S_n (12.5)	1.0969

14 Establish Initial Trial Binder Content

The initial trial binder content is established to provide a good starting point for the mix design process. The binder content is estimated based on the theoretical relationship between aggregate properties and volumetric properties of the mix.

Estimate the binder content that will result in the trial compacted specimens having air voids close to 4% at N_{des} by using the following steps:

1. Obtain the binder specific gravity (G_b)
2. Calculate bulk specific gravity of the aggregate blend (G_{sb}OD), and apparent specific gravity of the aggregate blend (G_{sa})
3. Estimate effective specific gravity of aggregate, G_{se_est}, using:
    - Oven-dry bulk specific gravity of the aggregate blend, G_{sb}(OD)
    - Apparent specific gravity of the aggregate blend, G_{sa}
4. Calculate volume of absorbed binder, V_{ba}
5. Calculate volume of effective binder, V_{be}
6. Calculate trial binder content, P_{bi}

15 Specific Gravity of Blend

The G_{sb}(OD) and G_{sa} (oven-dry bulk specific gravity and apparent specific gravity) of each blend are determined using the law of partial fractions in two different ways:

a) Measure the specific gravity of the individual stockpiles and use the stockpile percentages to determine the blend's specific gravity; or,

b) Measure the specific gravity directly on the trial blends.

Approach b) is more direct than a) because the measured specific gravity represents the exact blend, although the specific gravity would need to be determined again after any gradation changes.

Aggregate Specific Gravity Calculation 16

$$G_{sb}(OD) = \frac{P_1 + P_2 + P_3 + \dots\dots\dots P_n}{\frac{P_1}{Gsb(OD)_1} + \frac{P_2}{Gsb(OD)_2} + \frac{P_3}{Gsb(OD)_3} + \dots\dots\dots \frac{P_n}{Gsb(OD)_n}}$$

$$G_{sa} = \frac{P_1 + P_2 + P_3 + \dots\dots\dots P_n}{\frac{P_1}{Gsa_1} + \frac{P_2}{Gsa_2} + \frac{P_3}{Gsa_3} + \dots\dots\dots \frac{P_n}{Gsa_n}}$$

Where:

$P_1, P_2, P_3, \dots\dots P_n$ = Percentage of each aggregate used (totaling 100)

$G_1, G_2, G_3, \dots\dots G_n$ = Specific Gravity of each aggregate (bulk or apparent)

Calculation Examples using data from **Table 1 – Aggregate Blending Worksheet** 17

$$G_{sb}(OD) = \frac{100}{\frac{20}{2.643} + \frac{28}{2.641} + \frac{12}{2.589} + \frac{40}{2.610}} = 2.6226, \text{ say } 2.623$$

$$G_{sa} = \frac{100}{\frac{20}{2.673} + \frac{28}{2.676} + \frac{12}{2.689} + \frac{40}{2.677}} = 2.6774, \text{ say } 2.677$$

18

Estimated Effective Specific Gravity of Aggregate

The effective specific gravity of aggregate describes the ability of the aggregate blend to absorb the binder. It is calculated using an empirical relationship between the oven-dry bulk specific gravity and the apparent specific gravity of the blend. A highly absorptive aggregate absorbs more binder, which in turn reduces its effective specific gravity because the binder is lighter than the aggregate particles.

$$G_{se\_est} = G_{sb(OD)} + \left(0.8\left(G_{sa} - G_{sb(OD)}\right)\right)$$ 19

where:

G_{se_est} = Estimated effective specific gravity of the aggregate blend
$G_{sb}(OD)$ = Bulk specific gravity (oven-dry) of the aggregate blend
G_{sa} = Apparent specific gravity of the aggregate blend

Note: The 0.8 factor can be changed at the designer's discretion. Absorptive aggregates may require a factor closer to 0.5–0.6.

Calculation Example (Specific Gravity data from calculation examples on previous page)

20

$$G_{se\_est} = 2.623 + \left(0.8\left(2.677 - 2.623\right)\right) = 2.6662, \text{ say } 2.666$$

Estimated Volume of Absorbed Binder

Estimate the volume of binder absorbed into the aggregate
(First calculate the value of W_s, then V_{ba})

$$W_s = \frac{P_s(1 - V_a)}{\frac{P_b}{G_b} + \frac{P_s}{G_{se\_est}}}$$ 21

$$V_{ba} = W_s\left(\frac{1}{G_{sb}(OD)} - \frac{1}{G_{se\_est}}\right)$$

where:

W_s = Mass of aggregate (grams) in 1 cm^3 of mix
V_{ba} = Estimated volume (cm^3) of absorbed binder in 1 cm^3 of mix
P_s = Mass percent of aggregate estimated, in decimal equivalent (assumed to be 0.95)
V_a = Volume of air voids (assumed to be 0.04 cm^3 in 1 cm^3 of mix)
P_b = Mass percent of binder estimated, in decimal equivalent (assumed to be 0.05)
G_b = Specific gravity of the binder
G_{se_est} = Estimated effective specific gravity of the aggregate blend
$G_{sb}(OD)$ = Bulk specific gravity, oven-dry, of the aggregate blend

Estimated Volume of Effective Binder

Only the binder not absorbed into aggregate pores is available to bind the aggregates. This is referred to as the "effective binder."

$$V_{be} = 0.176 - (0.0675 \times \mathrm{Log}(S_n)) \qquad 22$$

V_{be} = Volume of Effective Binder
S_n = Nominal Maximum Size of aggregate blend (mm)

NOTE: This regression equation is derived from an empirical relationship between: (1) VMA and V_{be} when the V_a (air void content) is equal to 4.0 percent: V_{be}=VMA-V_a=VMA-4.0; and (2) the relationship between VMA and the nominal maximum sieve size of the aggregate in M 323.

Trial Binder Content

Using the binder specific gravity, calculated volumes of effective and absorbed binder, and mass of aggregate per cm^3 of mix, the trial binder content can be determined for each trial blend.

$$P_{bi} = 100\left[\frac{G_b(V_{be} + V_{ba})}{(G_b(V_{be} + V_{ba})) + W_s}\right] \qquad 23$$

where:

P_{bi} = Initial trial binder content (percent by weight of total mix)
G_b = Specific gravity of the binder
V_{be} = Estimated volume of effective binder
V_{ba} = Estimated volume of absorbed binder
W_s = Mass of aggregate (grams) in 1 cm^3 of mix

Mix design software can be used to determine the initial trial binder content for each trial aggregate blend. If necessary refer to Appendix X1 of AASHTO R 35.

Calculation Examples – (Using data from **Aggregate Blending Worksheet – Table 1)**

Mass of aggregate (grams) in one cm^3 of mix 24

Formula:

$$W_s = \frac{P_s(1 - V_a)}{\frac{P_b}{G_b} + \frac{P_s}{G_{se\_est}}}$$

Calculation Example:

$$W_s = \frac{(0.95)(0.96)}{\frac{0.05}{1.022} + \frac{0.95}{2.666}} = 2.2503927$$

Volume of absorbed binder (cm^3) in one cm^3 of mix 25

Formula:

$$V_{ba} = W_s\left(\frac{1}{G_{sb}(OD)} - \frac{1}{G_{se\_est}}\right)$$

Calculation Example:

$$V_{ba} = 2.2503927\left(\frac{1}{2.623} - \frac{1}{2.666}\right) = 0.0138378$$

Volume of effective binder (cm^3) in one cm^3 of mix 26

Formula:

$$V_{be} = 0.176 - (0.0675 \times \mathrm{Log}(S_n))$$

Calculation Example:

$$V_{be} = 0.176 - (0.0675 \times 1.0969) = 0.1019593$$

Estimated binder content for the trial mixture 27

Formula:

$$P_{bi} = 100\left[\frac{G_b\left(V_{be} + V_{ba}\right)}{\left(G_b\left(V_{be} + V_{ba}\right)\right) + W_s}\right]$$

Calculation Example:

$$P_{bi} = 100\left[\frac{1.022\ \left(0.1019593 + 0.0138378\right)}{\left(1.022\ \left(0.1019593 + 0.0138378\right)\right) +\ 2.2503927}\right] = 4.996,\ \text{say}\ \ 5.00$$

28 Compact Trial Blend Specimens

1. Prepare at least two replicate specimens at the initial trial binder content for each of the trial blends.

29 ***Note:*** 4500 to 4700 grams of aggregate will usually be sufficient to compact specimens of 110 to 120mm height. Trial specimens may be necessary.

2. Prepare replicate specimens for theoretical maximum specific gravity (G_{mm}) (FOP for AASHTO T 209).
3. Mix and condition the loose mix (FOP for AASHTO R 30).

30 **Mixing temperature: the middle of the range of temperature which the binder's kinematic viscosity is 0.17 ± 0.02 Pa-s.**

4. Obtain N_{ini}, N_{des} and N_{max} from Table 2 or the specifying agency.
5. Compact specimens to N_{des} (FOP for AASHTO T 312).
6. Determine the bulk specific gravity (G_{mb}) of each specimen (FOP for AASHTO T 166 or T 275).
7. Obtain the theoretical maximum specific gravity (G_{mm}) for each combination from the companion samples.

Note: *It may be advisable to compact an additional specimen to the N_{max} number of gyrations for each trial blend to assess conformance with the requirement at that number of gyrations. This will avoid continuing with a mixture that does not comply with all specified requirements.*

31 The Superpave volumetric mix design method uses gyratory compaction to fabricate the HMA specimens. The level of compaction in the Superpave Gyratory Compactor (SGC) is based on the design traffic that represents the 20-year design ESALs. The higher the design number of ESALs, the greater the number of required gyrations (See Table 2).

Table 2 – Superpave Gyratory Compaction Effort 32, 33

Design ESALS[1] (million)	Compaction Parameters			Typical Roadway Application[2]
	N_{ini}	N_{des}	N_{max}	
<0.3	6	50	75	Applications include roadways with very light traffic volumes such as local roads, county roads, and city streets where truck traffic is prohibited or at a very minimal level. Traffic on these roadways would be considered local in nature, not regional, intrastate, or interstate. Special purpose roadways serving recreational sites or areas may also be applicable to this level.
0.3 to <3	7	75	115	Applications include many collector roads or access streets. Medium-trafficked city streets and the majority of county roadways may be applicable to this level.
3 to <30	8	100	160	Applications include many two-lane, multilane, divided, and partially or completely controlled access roadways. Among these applications are medium to highly trafficked city streets, many state routes, US highways, and some rural interstates.
≥30	9	125	205	Applications include the vast majority of the US Interstate system, both rural and urban in nature. Special applications such as truck-weighing stations or truck-climbing lanes on two-lane roadways may also be applicable to this level.

(1) The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

(2) As defined by "A Policy on Geometric design of Highways and Streets, 1994, AASHTO.

Evaluate Compacted Trial Mixtures

Determine the volumetric requirements according to Table 3

V_a Calculation

(Air void is defined as the volume of the total HMA mix occupied by air in percent. It is calculated using the bulk specific gravity (G_{mb}) and the maximum theoretical specific gravity (G_{mm}).

34

$$V_a = 100 \times \left[1 - \left(\frac{G_{mb}}{G_{mm}}\right)\right]$$

Calculate Air Void Content for each blend:

VMA Calculation

(VMA is defined as the percent of volume of total mix that is not occupied by aggregate. It is the percent of volume of total mix occupied by the effective binder and air).

35

$$VMA = 100 - \left(\frac{G_{mb} P_s}{G_{sb}(OD)}\right)$$

Calculate Voids in Mineral Aggregate (VMA) for each blend:

Where:

G_{mb} = Bulk specific gravity of the extruded specimen
G_{mm} = Theoretical maximum specific gravity of the mix
P_s = Percent of aggregate in the mix = 100 - P_{bi}
$G_{sb}(OD)$ = Bulk specific gravity (oven-dry) of the combined aggregate

Calculation Examples:

36

$$V_a = 100 \times \left[1 - \left(\frac{2.348}{2.468}\right)\right] = 4.86\%$$

37

$$VMA = 100 - \left(\frac{(2.348)(95.00)}{2.623}\right) = 14.96\%$$

where:

G_{mm} = 2.468 Measured Theoretical Maximum Specific Gravity at Trial Binder Content
G_{mb} = 2.348 Measured Average Bulk Specific Gravity of the Compacted Specimens
P_s = 95.00 Percentage of Aggregate in the Trial Mixture
$G_{sb}(OD)$ = 2.623 Bulk Specific Gravity, oven-dry, of the Aggregate Blend

Evaluating Volumetric Mixture Properties 38

Although initial binder content was estimated for an air void content of 4.0% it is unlikely the actual air void content is exactly 4.0%. In this case, a change in binder content is needed to obtain 4.0% air voids. The VMA change caused by the binder content change is estimated. These calculations permit the evaluation of VMA and VFA of each trial blend gradation at the same design air void content, 4.0 percent. Mix design software is generally used for these adjustments.

Estimating the Volumetric Properties at 4.0 percent Air Voids

1. Determine the difference in average air void content at N_{des} and 4.0% (ΔV_a)

Difference in Air Voids 39

$$\Delta V_a = 4.0 - V_a$$

V_a = Air void content of the trial aggregate gradation at N_{des}
ΔV_a = Change in air void content

2. Estimate the change in binder content (ΔP_b) needed to change the air void content to 4.0%

Change in Binder 40

$$\Delta P_b = -0.4(\Delta V_a)$$

ΔP_b = Change in binder percent

3. Calculate the new estimated binder content (P_{b_est}) required to achieve 4.0% air voids

41

New Estimated Binder Content

$$P_{b\_est} = P_{bi} + \Delta P_b$$

P_{b_est} = Binder content estimated for 4.0% air voids
P_{bi} = Trial binder content actually used for blend
ΔP_b = Change in binder percent

4. Estimate the change in VMA (ΔVMA) caused by the change in air void content (ΔV_a) using the appropriate calculation below

42

Change in VMA

$$\Delta VMA = 0.2(\Delta V_a) \quad \textbf{For } V_a > 4.0\%$$

or,

$$\Delta VMA = -0.1(\Delta V_a) \quad \textbf{For } V_a < 4.0\%$$

5. Calculate the VMA at N_{des} and 4.0% air voids

43

VMA at N_{des}

$$VMA_{design} = VMA_{trial} + \Delta VMA$$

where:

VMA_{design} = VMA estimated at 4.0% air voids
VMA_{trial} = VMA at initial trial binder content

6. Using the value of ΔV_a estimate the relative density at N_{ini} when the air void content is adjusted to 4.0% at N_{des}

44

Relative Density

$$\%G_{mm\_initial} = 100 \times \left(\frac{G_{mb} h_d}{G_{mm} h_i} \right) - \Delta V_a$$

where:

$\%G_{mm\_initial}$	=	Relative density at N_{ini} at the adjusted binder content
h_d	=	Height of specimen after N_{des} gyrations
h_i	=	Height of specimen after N_{ini} gyrations

7. Calculate the actual Effective Specific Gravity (G_{se}) using measured G_{mm}

45

Actual Effective Specific Gravity

$$G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}}$$

where:

G_{se} = Actual effective specific gravity
G_{mm} = Measured theoretical maximum specific gravity of mixture
P_{mm} = Percent by mass of total loose mix = 100
P_b = Binder content at which G_{mm} was performed
G_b = Specific gravity of binder

8. Estimate the percent of effective binder (P_{be_est}) and calculate the dust-to-binder ratio

% Effective Binder 46

$$P_{be\_est} = -(P_s \times G_b)\left(\frac{G_{se} - G_{sb}(OD)}{G_{se} \times G_{sb}(OD)}\right) + P_{b\_est}$$

where:

P_{be_est}	= Estimated effective binder content
P_s	= Aggregate content, adjusted to 4.0% air voids = 100 - P_{b_est}
G_b	= Specific gravity of binder
G_{se}	= Actual effective specific gravity of aggregate
$G_{sb}(OD)$	= Bulk specific gravity, oven-dry, of the combined aggregate
P_{b_est}	= Estimated binder content to achieve 4.0% air voids

9. Estimate the dust to effective binder ratio 47

Dust to Binder Ratio:

$$\text{dust} - \text{to} - \text{binder} = \frac{P_{0.075}}{P_{be\_est}}$$

where:

$P_{0.075}$ = Percent passing the #200 sieve

Calculation Examples (Estimating Volumetric Properties at 4.0% Air Voids)

Given: 48

P_{bi}	= 5.00%	(from previous example, page 3-12)
V_a	= 4.86%	(from previous example, page 3-15)
VMA	= 14.96%	(from previous example, page 3-15)
$P_{0.075}$	= 4.8%	(minus No. 200 material from aggregate blend, page 3-5)
h_d	= 115.7 mm	(average height at N_{des} number of gyrations)
h_i	= 127.1 mm	(average height at N_{ini} number of gyrations)
G_{mb}	= 2.348	(measured average G_{mb} of extruded specimens)
G_{mm}	= 2.468	(measured G_{mm} of mix at P_{bi})
G_b	= 1.022	(binder specific gravity)

Difference in Air Voids 49

Difference in average air void content at N_{des} and 4.0% (ΔV_a)

Formula:

$$\Delta V_a = 4.0 - V_a$$

Calculation Example:

$$\Delta V_a = 4.0 - 4.86 = -0.86$$

V_a = air void content of the trial aggregate gradation at N_{des}
ΔV_a = change in air void content

Change in Binder Content

50

Estimated change in binder content (ΔP_b) needed to change the air void content to 4.0%

Formula:

$$\Delta P_b = -0.4(\Delta V_a)$$

Calculation Example:

$$\Delta P_b = -0.4(-0.86) = 0.34$$

ΔP_b = change in binder percent

Estimated Binder Content to Achieve 4.0% Air Voids 51

Calculate the new estimated binder content (P_{b_est}) required to achieve 4.0% air voids

Formula:

$$P_{b\_est} = P_{bi} + \Delta P_b$$

Calculation Example:

$$P_{b\_est} = 5.00 + 0.34 = 5.34$$

P_{b_est} = binder content estimated for 4.0% air voids

Change in VMA 52

Calculate the change in VMA at 4.0% air voids. Since V_a was greater than 4.0, use the appropriate formula

Formula:

$$\Delta VMA = 0.2(\Delta V_a)$$

Calculation Example:

$$\Delta VMA = 0.2(-0.86) = -0.17$$

ΔVMA = change in VMA

VMA at N_{des} 53

Calculate the VMA adjusted to 4.0 air voids in the mixture

Formula:

$$VMA_{design} = VMA_{trial} + \Delta VMA$$

Calculation Example:

$$VMA_{design} = 14.96 + (-0.17) = 14.79$$

VMA_{design} = VMA estimated at 4.0% air void
VMA_{trial} = VMA at initial trial binder content

Relative Density at N_{ini}

Using the value of ΔV_a estimate relative density at N_{ini} when the air void content is adjusted to 4.0% at N_{des}

Formula: 54

$$\%G_{mm\_initial} = 100 \times \left(\frac{G_{mb} h_d}{G_{mm} h_i} \right) - \Delta V_a$$

Calculation Example:

$$\%G_{mm\_initial} = 100 \times \left(\frac{2.348 \times 115.7}{2.468 \times 127.1} \right) - (-0.86) = 87.5$$

$\%G_{mm\_initial}$ = Relative density at N_{ini} at the adjusted binder content
h_d = 115.7 mm (Height of specimen after N_{des} gyrations)
h_i = 127.1 mm (Height of specimen after N_{ini} gyrations)
ΔV_a = –0.86 (Change in air void content)

Actual Effective Specific Gravity 55

Calculate the actual Effective Specific Gravity (G_{se}) using measured G_{mm}

Formula:

$$G_{se} = \frac{P_{mm} - P_b}{\dfrac{P_{mm}}{G_{mm}} - \dfrac{P_b}{G_b}}$$

Calculation Example:

$$G_{se} = \frac{100 - 5.00}{\dfrac{100}{2.468} - \dfrac{5.00}{1.022}} = 2.6666, \text{say } 2.667$$

where:
G_{se} = Actual effective specific gravity
G_{mm} = 2.468 (Measured Theoretical Maximum Specific Gravity)
P_{mm} = 100 (Percent by mass of total loose mix)
P_b = 5.00 (Binder Content at which G_{mm} was performed)
G_b = 1.022 (Binder Specific Gravity)

Percent Effective Binder 56

Estimate the percent of effective binder (P_{be_est})

Formula:

$$P_{be\_est} = -(P_s \times G_b)\left(\frac{G_{se} - G_{sb}(OD)}{G_{se} \times G_{sb}(OD)}\right) + P_{b\_est}$$

Calculation Example:

$$P_{be\_est} = -(94.66 \times 1.022)\left(\frac{2.667 - 2.623}{2.667 \times 2.623}\right) + 5.34 = 4.73$$

P_{be_est} = Estimated effective binder content
P_s = Aggregate content, adjusted to 4.0% air voids = 100 - P_{b_est}
G_b = Specific gravity of binder
G_{se} = Actual effective specific gravity of aggregate
$G_{sb}(OD)$ = Bulk specific gravity, oven-dry, of the combined aggregate
P_{b_est} = Estimated binder content to achieve 4.0% air voids

Dust to Binder Ratio: 57

Estimate the dust to effective binder ratio

Formula:

$$\text{dust} - \text{to} - \text{binder} = \frac{P_{0.075}}{P_{be\_est}}$$

Calculation Example:

$$\text{dust} - \text{to} - \text{binder} = \frac{4.8}{4.73} = 1.01$$

$P_{0.075}$ = Percent passing the #200 sieve

Select the Best Design Aggregate Structure 58

Select the aggregate grading that best complies with all required Superpave properties for the next phase of the mix design process: the Optimum Binder Selection.

Selection of Design Aggregate Structure (Example) 59

Volumetric Property	Trial Mixture (1/2” Nominal Maximum Aggregate) 20-year Project Design ESALs = 5 million			Criteria
	1	**2**	3	
	At initial trial binder content			
P_b(trial)	5.1	**5.0**	4.9	
$\%G_{mm\ initial}$ (trial)	88.4	**86.6**	85.0	
$\%G_{mm\ des}$ (trial)	95.9	**95.14**	94.2	
V_a at N_{des}	4.1	**4.86**	5.8	4.0
VMA_{trial}	13.9	**14.96**	15.9	
	Adjustments to reach design binder content (V_a=4.0% at N_{des})			
ΔV_a	-0.1	**-0.86**	-1.8	
ΔP_b	0.0	**0.34**	0.7	
ΔVMA	0.0	**-0.17**	-0.4	
	At the estimated design content (V_a=4.0% at N_{des})			
Estimated P_b (design)	5.1	**5.34**	5.6	
VMA (design)	13.9	**14.79**	15.5	≥14.0
$\%G_{mm\ initial}$ (design)	88.5	**87.5**	86.8	≤89.0

Notes: The top portion of this table presents measured densities and volumetric properties for specimens prepared for each trial aggregate blend at the initial trial binder content.

None of the specimens had an air void content of exactly 4.0 percent. Therefore, the procedures for adjustments were applied to: 1) estimate the design binder content at which V_a=4.0%, and 2) obtain adjusted relative density values at this estimated binder content.

The middle portion of this table presents the change in binder content (ΔP_b) and VMA (ΔVMA) that occurs when the air void content (V_a) is adjusted to 4.0 percent for each trial aggregate blend gradation.

The comparison of the VMA and densities at the estimated design binder content to the criteria in the last column shows that trial aggregate blend #1 does not have sufficient VMA (13.9% versus a requirement of ≥14.0). Trial blend #2 and Trial #3 meet the requirements for relative density and VMA and, in this example, either may be selected as the design aggregate gradation.

Trial Blend #2, shown in **bold**, was used for examples presented in the text.

2 **Selecting Optimum Binder Content**

The steps for selecting the optimum binder content are:

- Identify Mixtures
- Fabricate Specimens
- Compact Specimens to N_{des}
- Evaluate Volumetric properties at N_{des}
- Select Optimum Binder Content
- Compact Replicate Specimens to N_{max}
- Evaluate Volumetric Properties at N_{max}

3 **Identify mixtures**

Prepare a minimum of two replicate samples at each of the following four binder contents:

Estimated design binder content $P_{b\ est}$

0.5 percent below $P_{b\ est}$

0.5 percent above $P_{b\ est}$

1.0 percent above $P_{b\ est}$

4 **Fabricate and Compact Specimens**

- Mix and age specimens
  (FOP for AASHTO R 30)
- Select compactive effort (gyrations)
- Compact replicate specimens
  (FOP for AASHTO T 312)
  1. Minimum of 2 specimens at each of the 4 binder contents
  2. Compact the specimens to N_{des}

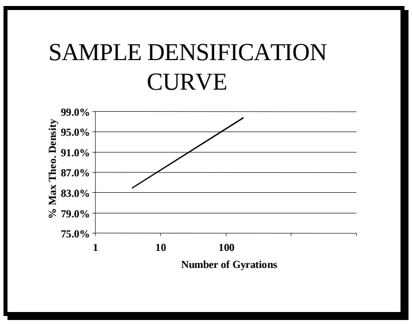
5 **Evaluate Volumetric Properties at N_{des}**

- Obtain height vs. number of gyrations for each specimen.
- Determine the bulk specific gravity (G_{mb}) of each specimen according to the FOP for AASHTO T 166 or T 275 as appropriate.
- Obtain the theoretical maximum specific gravity (G_{mm}) according to the FOP for AASHTO T 209 for each combination from separate samples that have been mixed and conditioned in the same manner as the compacted specimens.

6

- For each of the four mixtures prepare a densification curve, representing % G_{mm} versus number of gyrations.

7



8 **Volumetric Properties**

Using the data from the replicate specimens, calculate the following for each of the four mixtures:

- V_a
- VMA
- VFA
- $P_{0.075}/P_{be}$
- Density

Note: The volumetric properties are determined for each specimen and then averaged for each replicate mixture.

Calculate the Voids Filled with Asphalt (Binder)

$$VFA = 100 \times \left(\frac{VMA - V_a}{VMA} \right)$$ 9

Calculate the dust to binder ratio

$$\text{dust} - \text{to} - \text{binder} = \frac{P_{0.075}}{P_{be}} \tag{10}$$

where:

P_{be} = Effective binder content

Determine the average corrected specimen relative densities at N_{ini} (% $G_{mm\ initial}$) for each of the four mixtures

$$\%G_{mm_{initial}} = 100 \times \left(\frac{G_{mb} h_d}{G_{mm} h_i} \right) \tag{11}$$

where:

$\%G_{mm\ initial}$ = Relative density at N_{ini}
h_d = Height of specimen after N_{des} gyrations
h_i = Height of specimen after N_{ini} gyrations

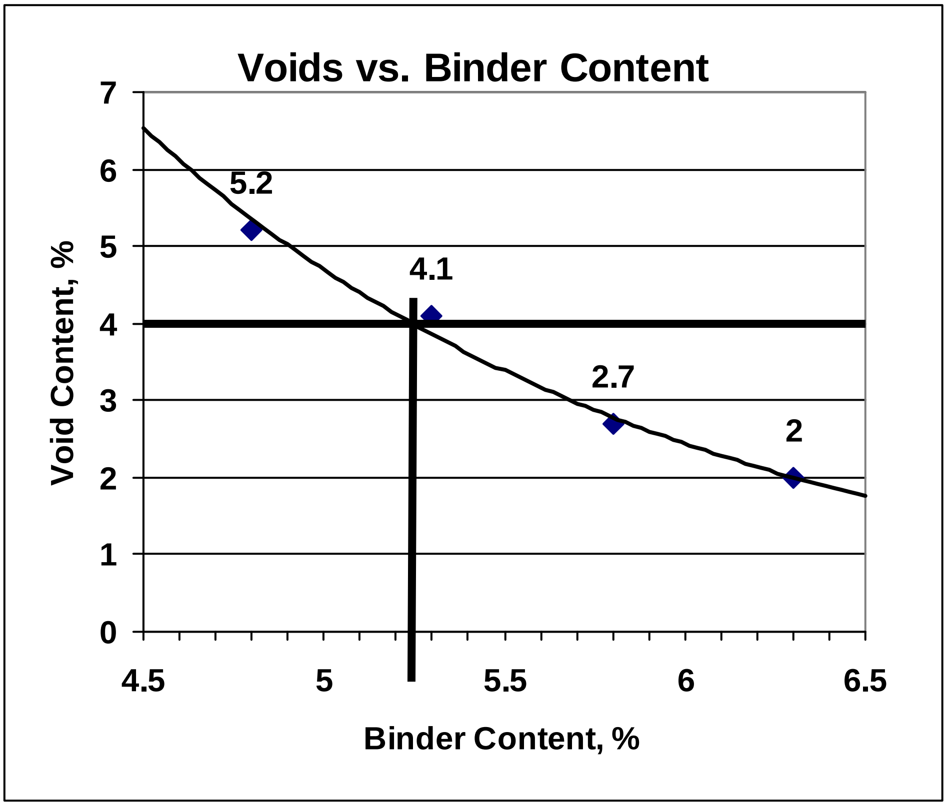
12 **Data Presentation**

- Plot the average V_a, VMA , VFA and relative density at N_{des} for replicate specimens versus binder content. Superpave software, or any spreadsheet software, can be used to generate the plots.

13 **Select Optimum Design Binder Content**

- Determine the binder content to the nearest 0.1 percent that corresponds with the target V_a of 4.0 percent, by graphical or mathematical interpolation. Report as the design binder content (P_b).

Air Voids (V_a) 14

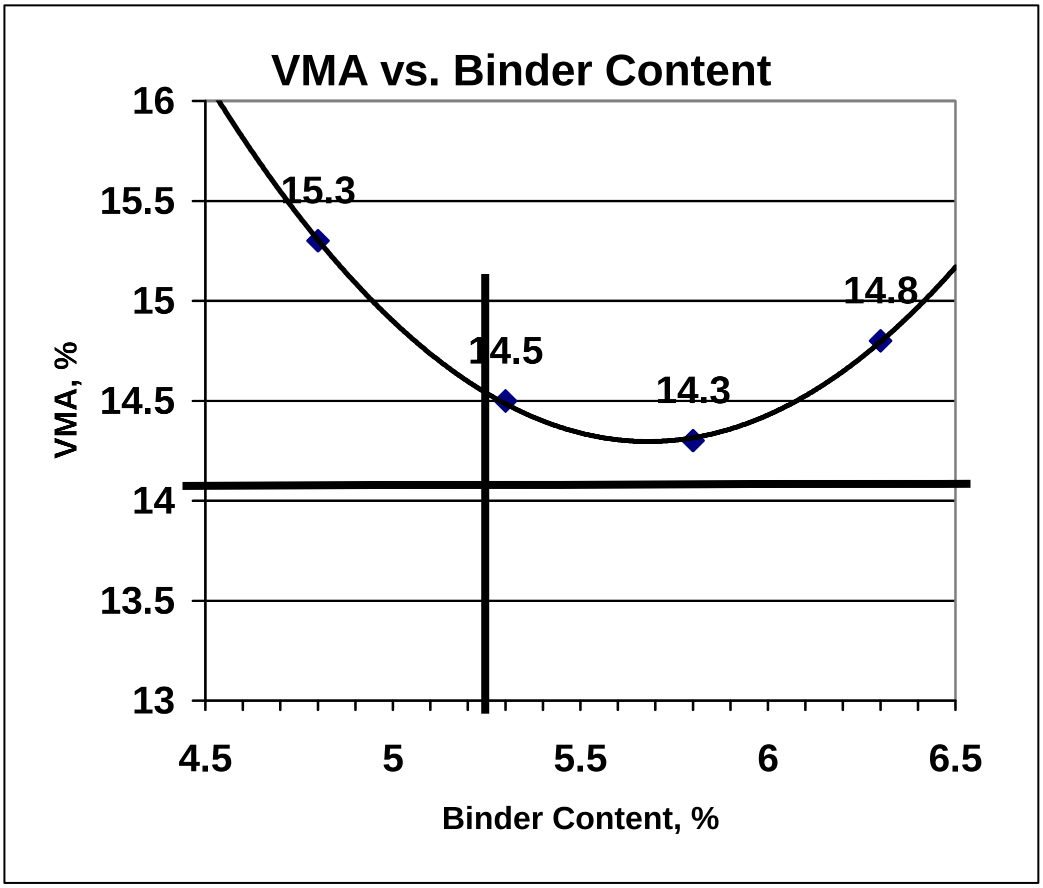


Air voids typically decrease as the percent binder content increases. On the graph the 4% V_a target is the horizontal line across the chart. The optimum binder content is the content at the point where the 4% criterion line intersects the air voids versus the binder content curve.

15 **Check Properties at Optimum**

- By interpolation or calculation obtain VMA, VFA, $P_{0.075}/P_{be}$ and density at the selected optimum binder content.
- Check the VMA, VFA and $P_{0.075}/P_b$ against the Superpave design criteria in Table 3.

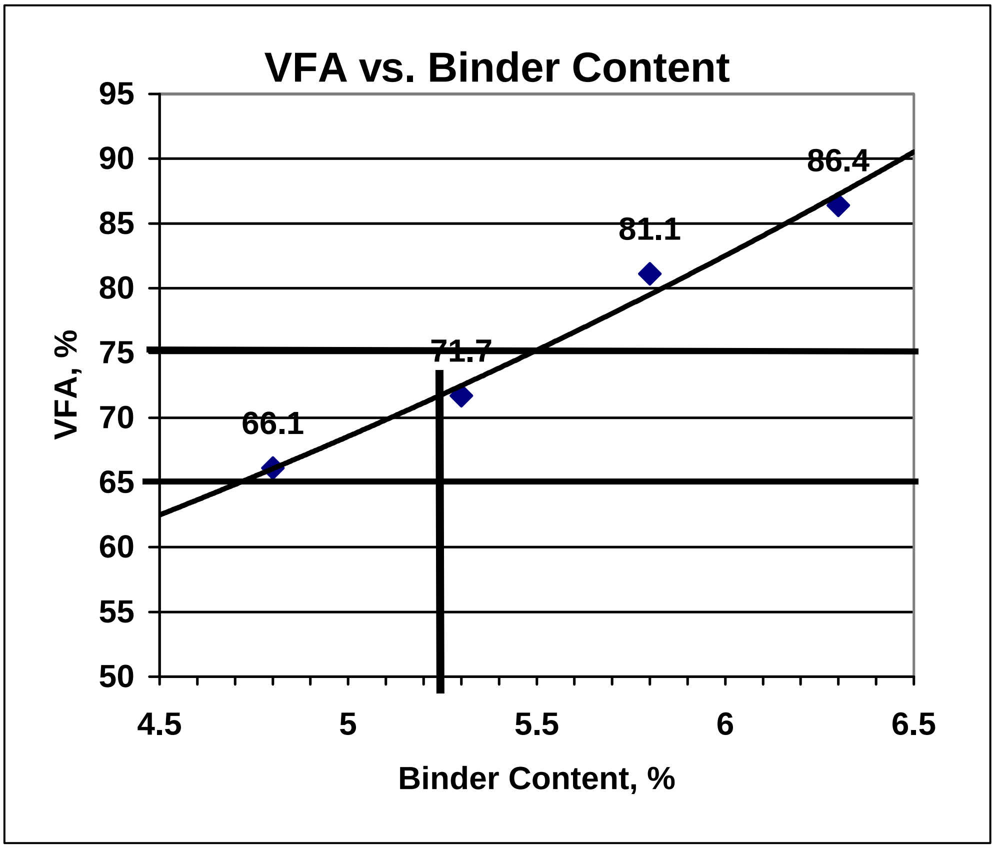
Voids in Mineral Aggregate (VMA) 16



The VMA decreases to a minimum value as binder content increases until the addition of more binder begins to push the aggregate apart, after which the VMA increases as more binder is added. On this graph the VMA target is shown as a horizontal line (14%) across the chart. In this example all mixtures meet the Superpave VMA criterion.

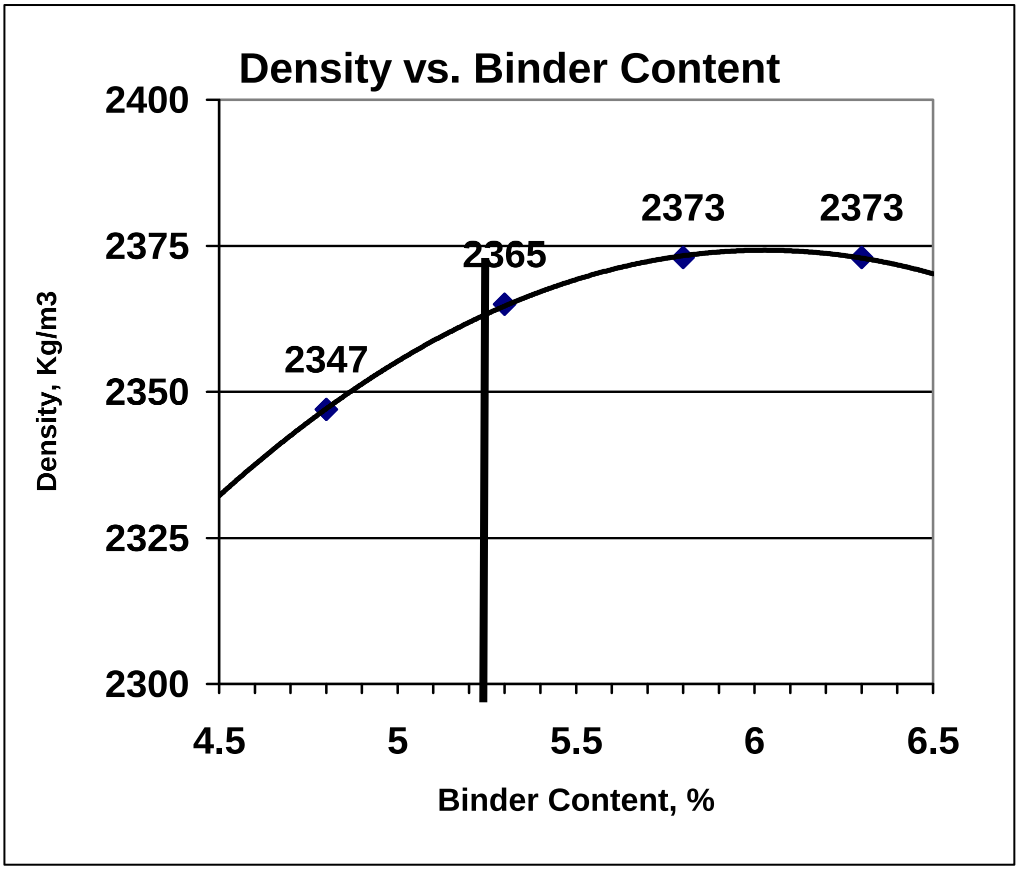
Voids Filled With Asphalt (Binder) (VFA)

17



The VFA increases as the binder content increases. On this graph the VFA criterion is shown in terms of a minimum and maximum line across the chart. The % VFA at the selected design binder content should fall within the VFA criterion lines.

Density at N_{des} 18



The density increases as the percent binder content increases up to a maximum and then it begins to decrease. This indicates that the binder is replacing the aggregate particles in the matrix.

19 **Determine % $G_{mm\ initial}$ at P_b**

1. Examine the plot of air void content versus binder content.
2. Determine the difference in air voids between 4.0 percent and the air void content at the nearest, lower binder content.
3. Determine the air void content at the nearest, lower binder content at its data point, not the line of best fit.
4. 20 Designate the difference in air void content as ΔV_a.
5. Determine the average corrected specimen relative density at N_{ini} at the nearest, lower binder content (below 4.0% air voids).
6. Calculate $\%G_{mm(initial)design}$. Confirm that the calculated value satisfies the design requirements in table 3 at the design binder content.

$$\%G_{mminitial} = 100 \times \left(\frac{G_{mb} h_d}{G_{mm} h_i} \right) \tag{21}$$

where:

$\%G_{mm\ initial}$ = Relative density at N_{ini}
h_d = Height of specimen after N_{des} gyrations
h_i = Height of specimen after N_{ini} gyrations

$$\%G_{mm(initial)design} = \%G_{mm(initial)} - \Delta V_a \tag{22}$$

where:

$\%G_{mm\ initial}$ =% G_{mm} at N_{ini} at the nearest lower binder content

Calculation Examples – (See Voids vs. Binder Content Data, page 3-29)

Calculate $\%G_{mm\ initial}$ at the nearest lower binder content (4.8% binder content)

where:

G_{mm} at 4.8% Binder Content	= 2.476
G_{mb} at 4.8% Binder Content	= 2.347
h_d at 4.8% Binder Content	= 115.7 mm
h_i at 4.8% Binder Content	= 127.5 mm

Formula:

$$\%G_{mm_{initial}} = 100 \times \left(\frac{G_{mb} h_d}{G_{mm} h_i} \right)$$

Calculation Example

$$\%G_{mm_{initial}} = 100 \times \left(\frac{2.347 \times 115.7}{2.476 \times 127.5} \right) = 86.0$$

Calculate $\%G_{mm(initial)design}$

where:

V_a at nearest lower binder content	= 5.2%
ΔV_a	= −1.2% (4.0 – 5.2)

Formula:

$$\%G_{mm(initial)design} = \%G_{mm(initial)} - \Delta V_a$$

Calculation Example:

$$\%G_{mm(initial)design} = 86.0 - (-1.2) = 87.2$$

23

24

Measure $\%G_{mm}$ at N_{max}

1. Prepare replicate specimens:
   a. Using the selected aggregate structure
   b. At the optimum binder content
2. Mix and condition the mixtures according to the FOP for AASHTO R 30.
3. Compact the specimens to N_{max} according to the FOP for AASHTO T 312.

25

4. Measure the bulk specific gravity (G_{mb}) of the replicate specimens.
5. Determine the average corrected specimen relative densities at N_{max} ($\%G_{mm\ max}$).
6. Confirm that $\% G_{mm\ max}$ satisfies the design requirements in Table 3 at the design binder content.

$$\%G_{mm\,max} = 100\frac{G_{mb}}{G_{mm}}$$

where:

$\%G_{mm\ max}$ = relative density at N_{max} gyrations at the design binder content

26 **Evaluate Moisture Susceptibility**

Evaluate moisture susceptibility by testing replicate specimens in accordance with the FOP for AASHTO T 283.

Note: If the tensile strength ratio is less than 0.80 then remedial action is required. If remedial agents are used such as anti-strip agents or mineral admixtures, retest the mix to assure compliance with the 0.80 minimum requirement and verify the volumetric properties.

27 **Check Superpave Criteria**

- Check all properties at the selected optimum binder content against the Superpave criteria:
  - –V_a
  - –VMA
  - –VFA
  - –$P_{0.075}/P_{be}$
  - –$\% G_{mm\ initial}$
  - –$\% G_{mm\ max}$
- Final design should meet all Superpave criteria in Table 3.

Table 3 – Superpave HMA Design Requirements 28

Design Esals[1] (million)	Required Relative Density (% of Theoretical Maximum Specific Gravity) N_{ini}	N_{des}	N_{max}	Voids in Mineral Aggregate[7] Percent Minimum — Nominal Maximum Aggregate Size 1½”	1”	3/4"	1/2"	3/8”	#4	% Voids Filled with Asphalt (VFA) Range[2]	Dust-to-Binder Ratio Range[3]
<0.3	≤91.5									70-80[4]	
0.3 to <3	≤90.5									65-78	
3 to <10		96.0[6]	≤98.0	11.0	12.0	13.0	14.0	15.0	16.0		0.6-1.2
10 to <30	≤89.0									65-75[5]	
≥30											

(1) The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.
(2) For 1½-inch nominal maximum size mixtures, the specified lower limit of the VFA range is 64% for all traffic levels.
(3) For #4 nominal maximum size mixtures, the dust-to-binder ratio shall be 0.9 to 2.0.
(4) For 1 inch nominal maximum size mixtures, the specified lower limit of the VFA shall be 67 percent for design traffic levels < 0.3 million ESALs.
(5) For design traffic levels >3 million ESALs, 3/8 inch nominal maximum size mixtures, the specified VFA range shall be 73 to 76 percent and for #4 nominal maximum size mixtures shall be 75 to 78 percent.
(6) Corresponds to an Air Void Content (V_a) of 4.0%.
(7) VMA greater than 2% above the minimum should be avoided.

Adjusting the Mixture to Meet Properties

29

Adjusting VMA. To change the design aggregate skeleton to meet specified VMA, there are three likely options:

1. Change the gradation, only if the trial aggregate blend gradation analysis did not include the full spectrum of the gradation control area.
2. Reduce or increase the minus #200 fraction, (reduction will increase VMA, increase will lower VMA). This is only viable if the minus #200 is not already at the lower or upper limits.
3. Change the texture and /or shape of the aggregate fractions; this would require further processing of existing material or a change in aggregate sources.

30 **Adjusting VFA.** The lower limit of the VFA range should always be met at 4.0 percent air voids if the VMA meet the requirements. If the VFA is too high then the VMA will be too high. If so, redesign the mixture to reduce VMA.

Options include:

1. Change gradation so that it is closer to the maximum density line.
2. Increase the minus #200 fraction if there is room within the specification control points.
3. Change the surface texture and shape of the aggregates.

31 **Adjusting the Tensile Strength Ratio.** The tensile strength ratio can be increased by:

1. Adding chemical anti-strip agents to the binder to promote adhesion in the presence of water.
2. Adding mineral admixtures.

32 Report

Project number
Traffic level
Mix design number
Design aggregate structure
- Source of aggregate
- Kind of aggregate
- Source and amount of RAP
- RAP quality characteristics and gradation

33 Design binder source and grade
HMA design characteristics:
- Percent binder
- Relative density
- N values
- VMA
- VFA
- V_a
- V_{be} and V_{ba}
- Dust-to-binder ratio

Tips! 34

- Check that the binder grade matches project climate conditions
- Be sure that aggregates obtained for the design accurately represent stockpiled materials
- Select compactive effort based on 20 year design ESAL's
- Select 3 trial blends encompassing the range of allowable gradations
- Condition G_{mm} samples the same as for compacted specimens 35
- Be sure that **all** volumetric properties are met before finalizing gradation selection
- Check and re-check all properties at P_b before reporting data

REVIEW QUESTIONS

1. Describe the aggregate preparation steps prior to combining to a target grading.

2. How is the combined aggregate grading determined for a trial gradation?

3. How many trial aggregate gradations must be prepared?

4. What constitutes an acceptable trial aggregate gradation?

5. For design ESAL's of 4 million, what is the number of gyrations used to compact the specimens during the aggregate selection phase, when the nominal maximum size is ¾ inch and the VMA required is 13.0%?

6. Calculate the VMA when traffic level is 2.8 million ESAL's, G_{mm} is 2.517, G_{mb} is 2.398, V_a is 4.7%, P_s is 95.2%, and G_{sb} is 2.639. Would this meet the requirements for a ½ inch nominal maximum size mix?

7. Given the above noted data, calculate V_a. How could this data be used in selection of binder content for a mix design?

8. Given the data from No. 6 above, calculate the VFA. Does this meet the requirements for a ¾ inch nominal maximum size?

9. Calculate the $\%G_{mm}$ at N_{max} for a compacted HMA specimen where the level of compaction was 205 gyrations, design ESAL's were 38 million, G_{mm} was 2.523, P_s was 95.9, G_{sb} was 2.714, and G_{mb} was 2.482. Does this comply with Superpave HMA Design Requirements?

Practice Practical – R 35 Trial Mixtures

Pavement parameters

Maximum seven-day average pavement design temperature: **50°C**.
Minimum pavement design temperature: **-20° C**.
20-year design ESAL's: **26 million**
Pavement Type: **Surface Course**
Traffic Speed: **Slow**

Given:

Binder Specific Gravity: **1.020**

Multiplier to be used for estimating effective aggregate specific gravity: **0.7**

Test Questions

1- Using the pavement parameters shown above, determine the required binder grade and number of gyrations for the project. Also indicate the binder grade required when 20% RAP is used. Record in the appropriate spaces on page 3-42.

2- Individual aggregate gradations specific gravities, and absorptions are given on the aggregate table (page 3-41). Using them, develop at least one gradation that meets the specified requirements for a mix having a nominal maximum size of: **3/4-inch (19 mm)**. Record the data for your gradation in the space shown for **"Comb. Grading."** Also calculate, and record in the space provided on the table, the combined specific gravities and absorption for your blend.

3- Using the specific gravities and the appropriate formulas from R 35, calculate and record estimated values of G_{se}, W_s, V_{ba}, V_{be}, and the trial binder content (P_{bi}). Space is provided on page 3-42 to record these values.

4- Using the trial mixture and compaction data for G_{mm}, height, and G_{mb} shown on page 3-42, calculate and/or record all values needed to evaluate the trial blend.

5- Calculate and record the volumetric properties adjusted to 4.0% voids.

6- Verify values meet the requirements of the FOP for AASHTO M 323.

Helpful information:

log 4.75	0.6767	log 19	1.2788
log 9.5	0.9777	log 25	1.3979
log 12.5	1.0969	log 37.5	1.5740

Available binders to choose from:

PG	52 -16	PG	58 -28	PG	64 -40
PG	52 -22	PG	58 -34	PG	70 -16
PG	52 -28	PG	58 -40	PG	70 -22
PG	52 -34	PG	64 -16	PG	70 -28
PG	52 -40	PG	64 -22	PG	70 -34
PG	58 -16	PG	64 -28	PG	70 -40
PG	58 -22	PG	64 -34		

Aggregate Blending Worksheet

Product Identification	Percentage of Products Used (Decimal)					
	Blend No. 1	**a** (3/4")	**b** (1/2")	**c** (3/8")	**d** (1/4")	**e** (Fine)
A (3/4")						
B (1/2")						
C (3/8")						
D (1/4")						
E (Fine)						
Total	1.00					

Grading for 3/4" (19 mm) Mix						
Sieve Size	Comb. Grading	Individual Product Contributions				
1"						
3/4"						
1/2"						
3/8"						
No. 4						
No. 8						
No. 16						
No. 30						
No. 50						
No. 100						
No. 200						
Combined Specific Gravity and Absorption						
G_{sb} (OD)						
G_{sb} (SSD)						
G_{sa}						
Absorption						

	Individual Product Identification and Gradations				
Sieve Size	**A** (3/4")	**B** (1/2")	**C** (3/8")	**D** (1/4")	**E** (Fine)
1"	100	100	100	100	100
3/4"	100	100	100	100	100
1/2"	10	91	100	100	100
3/8"	5	12	96	100	100
No. 4	3	2	20	75	100
No. 8	1	2	15	21	95
No. 16	1	2	5	10	78
No. 30	1	1	2	5	46
No. 50	1	1	2	3	25
No. 100	1	1	2	3	18
No. 200	0.2	0.3	1.5	2.0	10.3
Specific Gravity and Absorption					
G_{sb} (OD)	2.630	2.643	2.641	2.589	2.610
G_{sb} (SSD)	2.647	2.655	2.654	2.626	2.635
G_{sa}	2.676	2.673	2.676	2.689	2.677
Absorption	0.53	0.40	0.45	0.98	0.90

Trial Blend Properties

PG Binder Grade ______________ If 20% RAP is used? ______________

Mix Gyrations: N_{ini} __________ N_{des} __________ N_{max} __________

$G_{se\ est}$ __________ W_s __________

G_b __________ V_{ba} __________

P_{bi} __________ V_{be} __________

TRIAL MIXTURE AND COMPACTION DATA

G_{mm} 2.492

Gyratory Height Data

Specimen	1	2	Average
@N_{ini}	125.9	128.3	__________
@N_{des}	114.3	117.1	__________

Bulk Specific Gravity Data (G_{mb})

Specimen	1	2	Average
	2.367	2.359	__________

VOLUMETRIC SUMMARY OF TRIAL MIXTURE
(Calculate using appropriate values and formulas)

V_a _______ G_{se} _______ (actual G_{se}, not estimated value)

VMA _______ VFA _______

VOLUMETRIC SUMMARY OF TRIAL MIXTURE CORRECTED TO V_a OF 4.0%

$P_{b\ est\ design}$ _______ $\Delta\ V_a$ _______

VMA_{design} _______ $\Delta\ P_b$ _______

VFA_{design} _______ Δ VMA _______

$\%G_{mm\ initial}$ _______ P_s _______

$P_{be\ est}$ _______ Minus # 200 _______

Dust to Binder Ratio _______

Properties meet Superpave requirements (Yes/No) ________________

R 30

GUIDELINES FOR LABORATORY MIXING OF HOT-MIX ASPHALT (HMA) AND MIXTURE CONDITIONING OF HOT-MIX ASPHALT (HMA)

FOP AASHTO R 30

R 30

GUIDELINES FOR LABORATORY MIXING OF HOT-MIX ASPHALT (HMA) AND MIXTURE CONDITIONING OF HOT-MIX ASPHALT (HMA)

FOP AASHTO R 30

GUIDELINES FOR LABORATORY MIXING OF HOT-MIX ASPHALT (HMA) AND MIXTURE CONDITIONING OF HOT-MIX ASPHALT (HMA)
FOP AASHTO R 30

02 ## Significance

This FOP for laboratory mixing and short-term mixture conditioning of uncompacted hot-mix asphalt (HMA) simulates the pre-compaction phase of the construction process.

03 ## Scope

When HMA samples are prepared in the laboratory, proportions must be accurately controlled and properly combined by mixing followed by mixture conditioning. The mixture conditioning procedure allows for asphalt binder absorption to more accurately predict the properties and performance of HMA. Conditioning in the laboratory is not necessary prior to testing of plant-produced HMA.

This FOP describes only short-term aging of laboratory-mixed HMA intended for volumetric mixture design and mechanical property testing.

Apparatus

- **Oven(s) –** Forced-draft, capable of maintaining temperature up to 350°F.
- **Balance or Scale –** Of sufficient capacity and readable to 0.1 g.
- **Thermometer(s)** – Having a range from 120°F to 500°F and readable to 1°F.
- **Mixer –** Of sufficient capacity and design to adequately combine all ingredients.
- **Miscellaneous** – Metal pans, metal spatulas or spoons, timer and gloves, etc.

Mixing Procedure

04 ### General

Prepare a sufficient number of aggregate samples and quantity of asphalt binder to mix the required number of specimens and have one extra sample for a butter batch. Mixing temperature to be obtained from the Agency.

- Determine all masses to the nearest 0.1 g.

05

- Produce a mixture that contains thoroughly coated aggregate.
- Follow the applicable steps of the procedure listed below for the initial batch to butter the bowl and paddle or whip.
- After buttering, discard the butter batch and scrape bowl and paddle or whip to remove excess material.
- Follow the procedure for each subsequent batch.

06

Note 1: Aggregates may be heated to a temperature not greater than 50ºF above mixing temperature.

Note 2: Cover asphalt binder containers. When binder reaches mixing temperature stir it thoroughly. Asphalt binder may then be stored in an oven at mixing temperature for a short period of time, but must be adequately re-stirred immediately prior to use. Other heating apparatus may be used to maintain binder temperature provided it is demonstrated that uniformity in temperature is achieved without localized over-heating.

Discard unused asphalt binder after 4 hours of achieving mixing temperature. Do not reheat asphalt binder.

Mixing Procedure Steps

1. Heat aggregate, asphalt binder, bowl, whip and utensils in an oven regulated within the mixing temperature range until temperature has stabilized. Two to four hours are required for aggregate to reach mixing temperature (See Notes 1 and 2).
2. Prepare, mix and discard a butter batch.
3. Record mass of buttered bowl and paddle or whip.
4. Remove paddle or whip and zero balance with empty bowl. Introduce the aggregate and mix thoroughly.

07

5. Form a crater in the center of the aggregate and determine the aggregate mass.
6. Add sufficient asphalt binder to achieve the desired asphalt binder content expressed as a percent of total mix. Record the mass of aggregate and asphalt binder actually used for each batch.
7. Thoroughly mix for a minimum of two minutes, or until complete mixing has occurred.
8. Scrape material adhering to paddle or whip into the mixed HMA.

08

9. Examine the HMA for adequacy of mixing. If any aggregate has not been coated, mix by hand until HMA is properly coated.

Remove Sample From Bowl

Note 3: The tolerance for scraping the bowl to within 0.1% of mixed sample mass does not preclude cleaning to a closer tolerance. Be consistent in cleaning the apparatus from batch-to-batch to prevent influencing consecutively mixed samples.

10. Remove mix from bowl, scraping bowl clean. Place all HMA into a baking pan.
11. Record mass of empty bowl and paddle or whip. Ensure this mass agrees with the mass of the initial buttered bowl within at least 0.1% of the sample mass of the mixed HMA.

    Examples:

    4700 g HMA sample, 0.1% = 4.7 g

    2100 g HMA sample, 0.1% = 2.1 g
12. Age according to this FOP or other specified test procedure.

Procedures for Hydrated Lime and RAP

09 **Method A – Hydrated Lime Slurry Induction**

1. Prior to heating aggregate in step 1 of Mixing Procedure, add hydrated lime slurry (3:1 ratio of water to hydrated lime) to dry aggregate.
2. Mix until uniform (two minutes minimum).
3. Heat aggregate and lime to mixing temperature. Ensure aggregate has reached constant mass before mixing with asphalt binder.
4. Continue with Step 1 of mixing process.

10 **Method B – Lime Marination**

1. Prior to heating aggregate in step 1 of Mixing Procedure, add hydrated lime slurry (3:1 ratio of water to hydrated lime) to dry aggregate.
2. Mix until uniform (two minutes minimum).
3. Hold for 24 hours.
4. Heat aggregate and lime to mixing temperature. Ensure aggregate has reached constant mass before mixing with asphalt binder.
5. Continue with Step 1 of mixing process.

11 **Incorporation of Reclaimed Asphalt Pavement (RAP)**

Thirty minutes prior to mixing dry aggregates with asphalt binder (step 6 of Mixing Procedure), add RAP (at room temperature) to dry aggregate in step 1 of Mixing Procedure. Return to oven for remaining 30 minutes. Continue with mixing as above.

Mixture Conditioning Procedures

Spread Sample 1 – 2 in Thick

Forced Draft Oven

12 **Conditioning for Volumetric Mixture Design**

Short-term mixture conditioning for volumetric mixture design is conducted at compaction temperature (the middle range of temperature at which the asphalt binder's kinematic viscosity is 0.28 ± 0.03 Pa·s).

13 1. Place the mixture into a metal baking pan.

14 2. Spread the mixture in the baking pan evenly at 1 – 2 inch thick.

15 3. Place the mixture and pan in the forced-draft oven at compaction temperature for 2 hours ± 5 minutes. (If using modified asphalt, consult the supplier for the proper compaction temperature).

4. Stir the mixture after 60 ± 5 minutes to maintain uniform conditioning.

16 5. After 2 hours ± 5 minutes, remove the mixture from the oven.

6. The conditioned mixture is now ready for compaction or other required testing. Conduct required testing without delay.

17 **Conditioning for Mechanical Property Testing**

Pre-heat the mixture-conditioning oven to 275 ± 5ºF.

18 1. Place the mix in a pan of sufficient size for the volume of HMA required for the mechanical property testing.
2. Spread the mixture in the pan evenly at 1 – 2 inch thick.
3. Place the mixture and pan in the forced-draft oven at 275 ± 5ºF for 4 hours ± 5 minutes.

19 4. Stir the mixture every 60 ± 5 minutes to maintain uniform conditioning.
5. After 4 hours ± 5 minutes, remove the mixture from the oven.
6. The conditioned mixture is now ready for required mechanical test specimen preparation. Conduct required procedures without delay.

20 **Tips!**

- Be sure that all materials and mixing tools are heated within the mixing temperature range
- Remember to first mix and discard a butter batch
- Check that bowl is cleaned to within acceptable tolerance of initial buttered mass (0.1% of mass of HMA sample mixed)
- Record mass of aggregate and asphalt binder actually used for each sample to 0.1 g
- Plan mixing and conditioning so that HMA is used without delay

REVIEW QUESTIONS

1. Describe the procedure leading up to but prior to mixing a sample in the laboratory.

2. For laboratory mixing, how long may binder be left at mixing temperature? May binder be reheated and used for laboratory mixed specimens?

3. Describe the required laboratory mixing procedure.

4. How thick is the layer of HMA placed in the baking pan for mixture conditioning?

5. During mixture conditioning, how frequently is the sample stirred?

6. What is the duration of mixture conditioning for laboratory specimens; for plant mixed specimens?

7. For laboratory mixed specimens, what is the required mixture conditioning temperature?

T 312

STANDARD METHOD OF TEST FOR PREPARING AND DETERMINING THE DENSITY OF THE HOT MIX ASPHALT (HMA) SPECIMENS BY MEANS OF THE SUPERPAVE GYRATORY COMPACTOR

FOP FOR AASHTO T 312

T 312

STANDARD METHOD OF TEST FOR PREPARING AND DETERMINING THE DENSITY OF THE HOT MIX ASPHALT (HMA) SPECIMENS BY MEANS OF THE SUPERPAVE GYRATORY COMPACTOR

FOP FOR AASHTO T 312

STANDARD METHOD OF TEST FOR PREPARING AND DETERMINING THE DENSITY OF THE HOT MIX ASPHALT (HMA) SPECIMENS BY MEANS OF THE SUPERPAVE GYRATORY COMPACTOR

FOP FOR AASHTO T 312

02 Scope

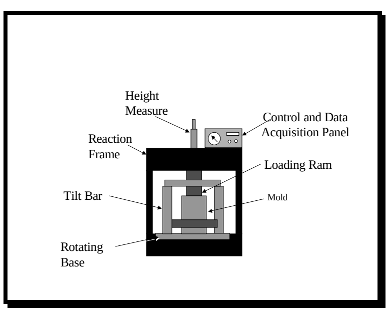
The Superpave gyratory compactor (SGC) is used to compact cylindrical specimens of hot-mix asphalt (HMA) by means of gyrations under a specified compressive stress and angle of inclination.

03 Significance

The procedure covers preparing specimens for determining the mechanical and volumetric properties of HMA. This procedure may also be used for field control of an HMA production process.

04 Apparatus

- Superpave Gyratory Compactor, with height measurement and recording device
- Molds, 150mm inside diameter and 250mm minimum height at room temperature
- Chute
- Scale
- Oven
- Miscellaneous



05 Gyratory Components

Refer to AASHTO T 312

- Reaction Frame
- Rotating base and Motor
- Loading System
  - Ram and Pressure gauge
- Height measure and recordation
- Molds, plates, etc.

06 Standardization

Calibration should be periodically verified on:

- Ram pressure (semi-annually)
- Angle of gyration (semi-annually)
- Gyration frequency (semi-annually)
- Height measure (semi-annually)
- Mold and plates (annually)

Angle of gyration refers to the effective internal angle. Internal angle is the angle formed between the internal mold diameter and a mold end plate, as a mold is gyrated in an SGC.

Effective internal angle is the average of the top and bottom angles and is verified according to AASHTO TP 71.

07 Equipment Preparation

Equipment preparation should be performed in accordance with manufacturer's recommendations, these should include:

- Warm-up equipment
- Verify settings
  - Angle
  - Pressure
  - Number of gyrations
- Lubricate bearing surfaces
- Prepare recording device
- Pre-heat molds and plates at compaction temperature (minimum of 30 min.)
- Pre-heat chute, spatulas and other apparatus (not to exceed compaction temperature, but may be lower to prevent damaging equipment)

08 Sample Preparation

Laboratory Prepared HMA

If laboratory mixed, prepare in accordance with the FOP for AASHTO R 30. If the specimens are to be used for the determination of volumetric properties, the sample size should be adjusted to result in a compacted specimen that is 115 ±5mm at the desired number of gyrations. It may be necessary to produce a trial specimen to determine the approximate testing size.

Plant produced HMA

Sample should be obtained in accordance with T 168 and reduced to testing size in accordance with R 47. The sample shall be brought to the compaction temperature range by careful, uniform heating in an oven immediately prior to molding.

Compaction Procedure

Superpave gyratory compactors may be different from that shown. Follow the manufacturers recommended loading procedure. This may require the steps performed in an order other than that discussed, i.e. the mold may be placed in a Pine / Brovold compactor prior to material being loaded into the mold.

09
1. Remove pre-heated mold and plate(s) from the oven.
2. Place base plate and paper disc in bottom of mold.

Note: Ensure plate(s) are correctly placed in the mold.

10
3. Mix sample with a heated spatula until it appears homogeneous.

11
4. Pour the mix into the mold all at once (care should be taken to avoid segregation or loss of material).

12
5. Level the mix in the mold.
6. Place a paper disc and the heated top-plate (if required) on top of leveled sample.

13

14
7. Load the mold into the compactor.
8. Ensure compactor is set to the specified number of gyrations or required specimen height.
9. Apply pressure: 600 kPa ±18 kPa
10. Apply angle: 1.16 ±0.02° average internal angle.
11. Apply the specified number of gyrations at a rate of 30 ±0.5 gyrations per minute.

15 Once the compaction is complete (after the specified number of gyrations), the compacted specimen is extruded from the mold and the paper discs removed. The compressed sample is then cooled down to room temperature, and the specimen is appropriately identified.

Note: A cooling period of 5-10 min. in front of a fan may be necessary for some HMA before extruding to insure the specimens are not damaged.

When reusing the mold it should be re-heated for a minimum of 5 minutes. Use of multiple molds will speed up the compaction process.

16 Density Procedure

Determine theoretical maximum specific gravity (G_{mm}) of the loose mix in accordance with the FOP for AASHTO T 209 using companion samples. Laboratory samples shall be prepared and conditioned in accordance with the FOP for AASHTO R 30. If the mix is plant produced conditioning is not required.

Determine the bulk specific gravity (G_{mb}) of the compacted specimen in accordance with the FOP for AASHTO T 166/T 275.

To calculate density, obtain the recorded specimen height to the nearest 0.1 mm after each revolution. This may be a printout or via computer data acquisition software.

Uncorrected Relative Density

The measured heights are used to calculate the density of the sample during the compaction process. These densities are referred to as the "uncorrected density" because they are estimated based on exact volume calculations. The formulas calculate volume in cm^3 to allow direct comparison with the specific gravity.

17 The uncorrected relative density may be calculated at any point in the compaction process using the equations at the left.

$$\%G_{mmux} = \frac{W_m}{V_{mx} \quad G_{mm} \quad G_m} \text{ x } 100$$

and

$$V_{mx} = \frac{\pi \ d^2 \ h_x}{4 \times 1000}$$

where:

$\%G_{mmux}$ = uncorrected relative density
W_m = mass of the specimen in g
G_{mm} = theoretical maximum specific gravity
G_m = unit wt. of water (1g/cm^3)
x = number of gyrations
V_{mx} = specimen volume, in cm^3 at any point based on diameter and height at that point (using mm for height and diameter)
h_x = height after x gyrations (mm)
d = diameter (mm)

18 **Corrected Relative Density**

$$\%G_{mmx} = \frac{G_{mb} \quad h_m}{G_{mm} \quad h_x} \text{ x } 100$$

The corrected relative density ($\%G_{mmx}$) may be determined for any point in the compaction of the specimens by using the formula at the left

where:

$\%G_{mmx}$ = corrected relative density as percent of maximum theoretical specific gravity

G_{mb} = measured bulk specific gravity of the compacted specimen

G_{mm} = theoretical maximum specific gravity

h_m = height of extruded specimen (mm)

h_x = height after x gyrations (mm)

Calculation Example – (Corrected Relative Density)

(Corrected Relative Density at N_{ini} for the specimen in Figure 1

$$\%G_{mmx}@N_{ini} = \frac{2.409 \times 118.0}{2.461 \times 133.1} \times 100 = 86.78,\ \text{say } 86.8$$ 19

Where:

N_{ini}	= 8 gyrations	N_{ini}	= 8
G_{mb}	= 2.409	N_{des}	= 100
G_{mm}	= 2.461	N_{max}	= 160
$\%G_{mmx}$	= corrected relative density		
h_x	= 133.1 mm (height after x gyrations)		
h_m	= 118.0 (height of extruded specimen)		

Figure 1 – Example Gyratory Printout 20

Specimen Size: 150 mm **Date: 11/01/04**

Pressure: 600 kPa **Time: 14:35:27**

Specimen ID: 1 **Test #1** **Technician**:

Specimen Height (mm) vs. No. of Gyrations

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	150.9	146.0	142.4	139.9	137.9	136.4	135.1	134.0	133.1	132.4
10	131.7	131.0	130.4	129.9	129.3	128.9	128.5	128.1	127.7	127.4
20	127.0	126.6	126.4	126.1	125.8	125.5	125.3	125.1	124.9	124.7
30	124.4	124.3	124.0	123.9	123.7	123.5	123.4	123.2	123.0	122.9
40	122.7	122.6	122.4	122.3	122.1	122.1	122.0	121.8	121.7	121.6
50	121.5	121.3	121.3	121.2	121.0	121.0	120.9	120.8	120.7	120.6
60	120.5	120.4	120.4	120.3	120.2	120.1	120.0	119.9	119.9	119.8
70	119.7	119.6	119.6	119.6	119.5	119.4	119.3	119.3	119.2	119.1
80	119.1	119.0	119.0	118.9	118.9	118.8	118.7	118.7	118.6	118.5
90	118.5	118.4	118.4	118.4	118.3	118.2	118.2	118.1	118.1	118.1
100	118.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
110	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
130	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
140	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
160	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
170	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
180	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
190	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

21 Report

Report on standard agency forms. If applicable to the agency requirements, include the following information:

1. Project name
2. Test date
3. Sample or lot and sublot number
4. Test location represented
5. Specimen I.D.
6. Job mix formula I.D.
7. 22 Percent binder to nearest 0.1%
8. Specimen mass to nearest 0.1g
9. G_{mm} to nearest 0.001
10. G_{mb} to nearest 0.001
11. Mold diameter to nearest 1.0mm
12. Height at each gyration to nearest 0.1mm
13. Relative density expressed as percent of G_{mm} to nearest 0.1%
14. Gyration angle to the nearest 0.01° and the method used to verify the angle

23 Tips!

- Don’t forget to install base plate and paper disc in bottom of mold prior to filling.
- Don’t forget to level the material in the mold.
- Cooling of extruded hot specimens is required in many cases to prevent damage due to handling.
- Don’t forget to remove the paper discs as soon as possible from the hot specimens.

REVIEW QUESTIONS

1. What is the purpose of the Gyratory Compactor?

2. How many kPa of pressure is applied to the specimen?

3. At what angle is the specimen compacted?

4. Using the example information calculate the corrected relative density ($\%G_{mmx}$) at N_{des}.

T 283

RESISITANCE OF COMPACTED BITUMINOUS MIXTURES TO MOISTURE INDUCED DAMAGE FOP FOR AASHTO T 283

T 283

RESISITANCE OF COMPACTED BITUMINOUS MIXTURES TO MOISTURE INDUCED DAMAGE FOP FOR AASHTO T 283

RESISITANCE OF COMPACTED BITUMINOUS MIXTURES TO MOISTURE INDUCED DAMAGE
FOP FOR AASHTO T 283

02
Scope

Moisture susceptibility of HMA mixtures is defined as the vulnerability of the mixture to be damaged by water. As moisture is collected within the HMA mixture, it can damage the bond between the asphalt binder and the aggregates resulting in stripping. The results from this FOP are used to evaluate the stripping susceptibility of the bituminous mixtures according to Superpave specifications.

T 283 contains instructions for preparing field-mixed samples for testing. That is beyond the scope of this FOP. Refer to T 283 for information regarding such samples.

03
Significance

This procedure is intended to evaluate the effects of saturation and accelerated water conditioning of compacted HMA mixtures in the laboratory.

04
Apparatus

- Superpave Gyratory Compactor.
- Equipment for preparing and compacting from the FOP for AASHTO T 312.
- Vacuum chamber capable of holding 6-inch (150mm) nominal diameter specimens submerged in water.
- Vacuum pump and manometer
- Distilled or de-ionized water.
- Heavy-duty leak-proof plastic bags, plastic film (Saran Wrap or equivalent) and tape.
- Freezer capable of 0 ±5°F.
- Water bath capable of 140 ±2°F.
- Water bath capable of 77 ±1°F.

- Apparatus capable of performing indirect tensile strength test, with a load speed of 2 inches per minute.
- Steel loading strips, 3/4 inch wide for 6-inch nominal (150mm) diameter specimens.
- Forced-draft ovens.
- Pans, 75-200 in^2, approximately 1 inch deep.

05

Determination of Sample Size

Determine the theoretical maximum specific gravity (G_{mm}), of the aged design mix according to the FOP for AASHTO T 209.

Determine the mass of mixture required at design asphalt binder content for a 150mm x 95mm specimen at 7% air voids using weight/volume relationships:

- Uncorrected mass of mix = $(0.93)(G_{mm})(1679)$
- The typical factor is near 0.91 for corrected (measured) density

Prepare a few trial specimens using the Superpave Gyratory Compactor to obtain the desired void content of 7 ± 0.5 percent. Adjust the mass of the mix by making correction to the typical factor (such as 0.91) to get to within the air void limits.

06

Sample Preparation

Prepare laboratory mixed samples in accordance with the FOP for AASHTO R 30, modified as follows:

- **Immediately** after mixing, the mixture shall be placed in a pan having a surface area of 75-100 square inches in the bottom and a depth of approximately 1 inch, and cooled at room temperature for 2 ±0.5 hours.
- Place the mixture in a 140 ±5° F oven for

16 ±1 hours for curing. (Pans should be placed on spacers to allow air circulation under the pan if the shelves are not perforated).

- Subject the cured mixture to the short-term aging procedure according to R 30 and immediately compact the mixtures.
- If plant produced HMA is used, sample should be obtained in accordance with T 168 and reduced to testing size. Bring the sample to compaction temperature ±5° F by careful, uniform heating in an oven immediately prior to molding.

07
- Compact at least six specimens for each test in accordance with the FOP for AASHTO T 312 to the air void content of 7 ±0.5% and a height of 95 ±5mm.
- After compacting, remove specimens from the molds and store for 24 ±3 hours at room temperature.

08
- Determine the specimen diameter to the nearest 0.05 inch by averaging a minimum of two measurements taken at right angles to each other at approximately mid height of the specimen.
- Determine the specimen thickness "t" to the nearest 0.05 inch by recording four measurements at approximately quarter points on the periphery of the specimen.

09
- Determine the bulk specific gravity (G_{mb}) of each of the compacted specimens in accordance with Method "A" of the FOP for AASHTO T 166. Calculate the air void content in percent (P_a) for each specimen, using the formula at the left.
- Sort specimens into subsets where the average void content of each subset is nearly equal.

$$P_a = 100\left(1 - \frac{G_{mb}}{G_{mm}}\right)$$

where:

P_a = Percentage of air voids (nearest 0.1%)
G_{mm} = maximum specific gravity (T209)
G_{mb} = Bulk specific gravity (T166)

Calculation Example 10

Bulk Specific Gravity of Compacted Specimens

Percentage of Air Voids and Sorting into Subsets

I.D. No.	Dry Mass (A)	SSD Mass	Submerged Weight	Volume (E)	Bulk Specific Gravity (G_{mb})	Theoretical Max. Sp. Gravity (G_{mm})	Percent Air Voids (P_a)
1	3619.9	3625.2	2098.5	1526.7	2.371	2.552	7.1
2	3587.5	3596.4	2076.9	1519.5	2.361	2.552	7.5
3	3603.2	3610.0	2087.1	1522.9	2.366	2.552	7.3
4	3641.2	3647.8	2116.6	1531.2	2.378	2.552	6.8
5	3594.6	3601.9	2080.7	1521.2	2.363	2.552	7.4
6	3634.3	3642.8	2113.2	1529.6	2.376	2.552	6.9
Unconditioned Subset S_1 (Specimens 1, 2, & 6)							**7.2**
Conditioned Subset S_2 (Specimens 3, 4, & 5)							**7.2**

Compacted specimens were sorted to result in average air voids being nearly equal for both the conditioned and unconditioned subsets.

Calculation Example 11

Percentage Air Voids

$$P_a = 100\left(1 - \frac{2.363}{2.552}\right) = 7.41\text{, say } 7.4\%$$

where:

G_{mb} = 2.363 (Specimen No. 5 from Table above)
G_{mm} = 2.552

Preconditioning

12 Precondition one of the subsets by subjecting the specimens to moisture saturation followed by a freeze-thaw cycle. **The other subset is not conditioned.** The specimens of the unconditioned subset are stored at room temperature thus allowing air-drying.

13 Saturation of Specimens

Vacuum saturate the conditioned subset:

- Place specimens in vacuum container over a spacer.
- Fill container with distilled water until 1 inch above specimen.

- Apply vacuum of 13-67 kPa absolute pressure, (10-26 inch Hg partial pressure), for 5-10 minutes.
- Remove vacuum and leave sample in water for 5-10 minutes.
- Determine SSD mass of specimen by AASHTO T 166, Method A.

Determining Degree of Saturation

Calculate Volume of Air Voids

Calculate the volume of air voids using the formula at the left.

(See the sample calculations below for examples)

$$V_a = \frac{P_a\ E}{100}$$

14

where:

V_a = volume of air voids, cm^3
P_a = air voids, percent
E = specimen volume, cm^3

Calculation Example 15

Volume of Air Voids

I.D. No.	Percent Air Voids (P_a)	Specimen Volume, cm^3 (E)	Volume of Air Voids, cm^3 (V_a)
3	7.3	1522.9	111.2
4	6.8	1531.2	104.1
5	7.4	1521.2	112.6

For specimen number 5, volume of air voids is calculated as shown:

$$V_a = \frac{7.4 \times 1521.2}{100} = 112.57,\ \text{say}\ 112.6\ cm^3$$

where:

P_a = 7.4% (percent air voids, see previous calculation example)
E = 1521.2 cm^3 (volume of specimen, from bulk specific gravity calculation)

16

$$J' = B' - A$$

where:

J' = volume of absorbed water, cm^3
B' = SSD mass after partial saturation, g
A = original dry specimen mass, g

Calculate Volume of Absorbed Water

- Calculate the volume of absorbed water according to the formula at the left. The difference between the partially saturated SSD mass (grams) and the original dry mass of the unsaturated specimen represents the volume of absorbed water.

Calculation Example 17

Volume of Absorbed Water

I.D. No.	Original Dry Mass, grams (A)	Partially Saturated SSD Mass, grams (B')	Volume of Absorbed Water, grams (J')	Volume of Air Voids, cm^3 (V_a)
3	3603.2	3685.8	82.6	111.2
4	3641.2	3717.8	76.6	104.1
5	3594.6	3673.9	79.3	112.6

Data for the conditioned subset is summarized in the table above. For individual specimen number 5, calculations for volume of absorbed water and degree of saturation are as shown below:

$$J' = 3673.9 - 3594.6 = 79.3 \text{ cm}^3$$

where:

B' = 3673.9 grams (partially saturated SSD mass, AASHTO T 166, Method “A”)

A = 3594.6 grams (original dry specimen mass)

18

$$S' = \frac{100\ J'}{V_a}$$

where:

S' = degree of saturation, %

Calculate Degree of Saturation

- The degree of saturation represents the percent of total specimen air void volume filled with water.
- Calculate degree of saturation according to the formula at the left.

Calculation Example 19

Degree of Saturation

$$S' = \frac{100 \times 79.3}{112.6} = 70.43 \text{ say } 70.4\%$$

where:

J' = 79.3 cm^3 (from previous example)
V_a = 112.6 cm^3 (from previous example)

20

Evaluate Degree of Saturation

- If S' is less than 70%, repeat the saturation process using more vacuum and/or time.
- If S' is more than 80%, specimen is damaged and must be discarded. Repeat the entire process using less vacuum and/or time.

Calculation Example

Evaluate Degree of Saturation

I.D. No.	Original Dry Mass, grams (A)	Partially Saturated SSD Mass, grams (B')	Volume of Absorbed Water, grams (J')	Volume of Air Voids, cm^3 (V_a)	Degree of Saturation, % (S')
3	3603.2	3685.8	82.6	111.2	74.3
4	3641.2	3717.8	76.6	104.1	73.6
5	3594.6	3673.9	79.3	112.6	70.4

Examination of the data reveals that all specimens have been saturated to the required range of 70 to 80%; therefore, testing may continue.

21

Freeze conditioning

Apply the following steps on the conditioned subset:

- Cover each of the vacuum saturated specimens with a plastic film (Saran Wrap).
- Place each wrapped specimen in a plastic bag containing 10 ±0.5 mL of water and seal the bag.
- Place the plastic bag containing the specimens in a freezer at a temperature of 0 ±5° F for a minimum of 16 hours.

22

Thaw Conditioning

Immediately following the freeze cycle, the specimens are subjected to a thaw period by placing them in a hot water bath for 24 hours. The process allows the water in the specimens to thaw and permits any emulsification damage to the binder to occur at the elevated temperature of 140° F.

Thaw the specimens by the following steps:

- Remove specimens from freezer.
- Place specimens in a bath containing potable water at 140 ±2° F for 24 ±1 hours. Specimens should have a minimum of 1-inch cover. Place specimens on a perforated support that will not allow them to deform during subsequent handling, but will permit free access of water.
- Remove bags and plastic wrap as soon as possible.
- After the 24 hours at 140° F, immediately place specimens in a water bath at 77 ±1° F for 2 hours ±10 minutes.
- Ice may be needed to keep the water bath at 77° F.
- Water bath should reach 77° F within 15 minutes.

23 **Determine Indirect Tensile Strength**

Place the dry unconditioned subset in heavy-duty, watertight plastic bags and immerse in a 77 ±1° F water bath for 2 hours ±10 minutes prior to testing.

Test conditioned and unconditioned subsets as follows.

- Determine the specimen thickness of the conditioned subset (t') by recording four measurements at the approximate quarter points on the periphery.

Determine the indirect tensile strength of unconditioned and conditioned specimens.

- Place specimen between the steel loading strips.
- Place specimen and loading strips between the bearing plates.
- Apply a load along the diameter of the specimen at a constant rate of 2 inches per minute.
- Measure the maximum load, (lb_f).

24

- Calculate the indirect tensile strength of each specimen in the unconditioned subset (S_1) according to the formula at the left.
- Calculate the indirect tensile strength of each specimen in the conditioned subset (S_2) according to the formula at the left, substituting the value of t' for specimen thickness.

$$S_t = \frac{2\,P}{\pi\, t\, D}$$

where:

S_t = indirect tensile strength, psi
P = maximum load, lbf
π = pi (3.14)
t = specimen thickness, inch
D = specimen diameter, inch (nearest 0.05”)

Calculation Example

Indirect Tensile Strength

25

I.D. No.	Specimen Diameter, inch (D)	Specimen Thickness, inch (t)	Specimen Thickness, inch (t')	Total Load, lb_f (P)	Indirect Tensile Strength (S_t)
1	5.90	3.80	-----	4190	119
2	5.90	3.65	-----	4230	125
6	5.90	3.80	-----	5105	145
Average, Subset 1 (Unconditioned)					**130**
3	5.90	3.75	3.80	3980	113
4	5.90	3.70	3.70	3540	103
5	5.90	3.75	3.80	3840	109
Average, Subset 2 (Conditioned)					**108**

For specimen number 5, indirect tensile strength (S_t) is calculated as follows:

$$S_t = \frac{2 \times 3840}{3.14 \times 3.80 \times 5.90} = 109.1, \text{ say } 109 \text{ psi}$$

where:

P = 3840 lb_f (maximum load at failure)
π = 3.14
t' = 3.80 inch (average of four measurements along periphery)
D = 5.90 inch (average of two measurements, mid height, right angle to each other)

Note: For the conditioned subset, values for S_t are calculated using t' for specimen thickness

$$TSR = \frac{S_2}{S_1}$$

where:

TSR = Tensile Strength Ratio

S_1 = average tensile strength, unconditioned subset

S_2 = average tensile strength, conditioned subset

26 **Tensile Strength Ratio**

- The moisture sensitivity of HMA mixtures is determined as a ratio of the tensile strength of the conditioned specimens divided by the tensile strength of the unconditioned specimens.
- Calculate the tensile strength ratio using the average indirect tensile strength of each subset, according to the formula at the left.
- For Superpave compliance, the TSR must be 0.80 or higher.

Calculation Example 27

Tensile Strength Ratio

Using the data from calculation of the Indirect Tensile Strength shown previously, calculate the Tensile Strength Ratio (TSR) as shown below:

$$\mathrm{TSR} = \frac{108}{130} = 0.831,\ \text{say}\ \ 0.83$$

where:

TSR = Tensile Strength Ratio
S_1 = 130 psi (average tensile strength of unconditioned subset)
S_2 = 108 psi (average tensile strength of conditioned subset)

28

Estimate Moisture Damage

- After recording the maximum stress for a given specimen, continue loading until a vertical crack appears. Remove the specimen from the machine and pry apart at the crack.
- Inspect the interior surface for evidence of cracked or broken aggregate; visually estimate the approximate degree of moisture damage on a scale from “0” to “5” (with 5 being the most stripped) and record the observations on the report.

29

Report

- Report on standard agency forms
- Number of specimens in each subset
- Average air voids in each subset
- Average degree of saturation of the conditioned subset
- Tensile strength of each specimen
- Tensile strength ratio
- Degree of stripping “0” to “5”
- Results of observation of cracked or broken aggregate

Tips! 30

- It is necessary to accurately measure specimen dimensions
- Compact trial specimens to determine needed proportions for achieving 7% air voids
- Remember to leave the specimens in the vacuum chamber for an additional 5 to 10 minutes after removal of vacuum
- Keep unconditioned subset at room temperature, then seal in water-tight bag and submerge in 77° F water bath for 2 hours prior to test
- Don’t forget the supports under the specimens during the hot-water conditioning

Sample Report

Project ____

Additive ______________________________ Amount ____________

Compaction Method ______________________ Effort ____________

Date Tested _______________ By ___________________________

Sample Identification		1	2	3	4	5	6
Diameter, in.	D	5.90	5.90	5.90	5.90	5.90	5.90
Thickness in.	t	3.80	3.65	3.75	3.70	3.75	3.80
Dry Mass in Air, g	A	3619.9	3587.5	3603.2	3641.2	3594.6	3634.3
SSD Mass, g	B	3625.2	3596.4	3610.0	3647.8	3601.9	3642.8
Weight in Water, g	C	2098.5	2076.9	2087.1	2116.6	2080.7	2113.2
Volume (B – C), cc	E	1526.7	1519.5	1522.9	1531.2	1521.2	1529.6
Bulk Specific Gravity (A/E)	G_{mb}	2.371	2.361	2.366	2.378	2.363	2.376
Maximum Specific Gravity	G_{mm}	2.552	2.552	2.552	2.552	2.552	2.552
%Air Voids [100(G_{mm} - G_{mb})/G_{mm}]	P_a	7.1	7.5	7.3	6.8	7.4	6.9
Volume of Air Voids (P_a E/100), cc	V_a	108.4	114.0	111.2	104.1	112.6	105.5
Load, lb_f	P	4190	4230	3980	3540	3840	5105
Saturated _____ min @ _____ psi, or _____ in Hg							
Thickness, in.	t'	-----	-----	3.80	3.70	3.80	-----
SSD Mass, g	B'	-----	-----	3685.8	3717.8	3673.9	-----
Vol. of Absorbed Water (B' – A), cc	J'	-----	-----	82.6	76.6	79.3	-----
% Saturation (100 J'/V_a)	S'	-----	-----	74.3	73.6	70.4	-----
Dry Strength (2 P/B t D), psi	S_t	119	125	-----	-----	-----	145
Average Dry Strength, psi	S_1	130					
Average Air Voids S_1, %		7.2					
Wet Strength (2 P/B t' D), psi	S_t	-----	-----	113	103	109	
Average Wet Strength, psi	S_2	108					
Average Air Voids S_2, %		7.2					
Average Saturation S_2, %		72.8					
Visual Moisture Damage (0 to 5)		-----	-----	1	2	1	-----
Cracked/Broken Aggregate							
TSR (S_2/S_1)		**0.83**					

REVIEW QUESTIONS

1. What is this procedure intended to evaluate?

2. Describe the method of compaction for this procedure. To what void content must specimens be compacted?

3. How many specimens are needed for this test?

4. How are they sorted after compaction? How would you sort specimens that have percent air voids (P_a) of 7.2, 7.3, 6.8, 6.7, 7.5, 7.0?

5. Describe thaw conditioning in detail.

6. How many freeze cycles is the unconditioned subset subjected to? The conditioned subset?

7. Given the following, calculate the Tensile Strength Ratio. Average diameter of specimens = 149.9 mm; average height of specimens = 95.2 mm; average strength of unconditioned subset = 132 psi; average strength of conditioned subset = 98 psi. Does this meet the needed criterion for Superpave?

T 324

HAMBURG WHEEL-TRACK TESTING OF COMPACTED HOT-MIX ASPHALT (HMA)

FOP FOR AASHTO T 324

T 324

HAMBURG WHEEL-TRACK TESTING OF COMPACTED HOT-MIX ASPHALT (HMA)

FOP FOR AASHTO T 324

HAMBURG WHEEL-TRACK TESTING OF COMPACTED HOT-MIX ASPHALT (HMA) FOP FOR AASHTO T 324

02

Scope

This FOP describes the AASHTO test method to test the rutting and moisture-susceptibility of hot-mix asphalt (HMA) samples in the Hamburg Wheel-Tracking Device.

03

Significance

Compacted samples of HMA are submerged in a temperature controlled water bath and tested under a concentrated load by a reciprocating rolling-wheel device. The rut depth and number of passes are measured. The performance of the HMA is evaluated, to determine the failure susceptibility of the HMA due to weakness in the aggregate structure, inadequate binder stiffness, or moisture damage.

Apparatus

04
- Hamburg Wheel-Tracking Machine.
- Temperature Control System – a water bath capable of controlling the temperature within ±1.0°C (1.8°F) over a range of 25 to 70°C (77 to 158°F).

05
- Impression Measurement System – An LVDT (Linear Value Displacement Transducer) capable of measuring the depth of the impression of the wheel within 0.01 mm.
- Wheel pass counter.
- Specimen Mounting System.
- Balance.
- Ovens.
- Superpave Gyratory Compactor.
- Bowls, spoons spatula etc.

Note 1: For more complete description of the required apparatus refer to AASHTO T 324.

06 Calibration / Equipment Verification

- Water bath temperature is within ±1°C (1.8°F) of the temperature readout (every six months).
- The LVDT height is within ±0.05mm (0.002in) between the three calibration blocks (10mm, 20mm, and 30mm) (0.4 inch, 0.8 inch, and 1.2 inch).
- The load on the wheel is 705 ±4.5N (158 ±1.0 lb) in the middle of the stroke at the correct elevation.
- The wheel reciprocates, back and forth, at 50 ±5 passes per min.

07 Specimen Preparation

Two test specimens are prepared for each test. The specimens may be either slab or cylinders.

Prepare laboratory mixed samples in

accordance with the FOP for AASHTO R 30.

If plant produced HMA is used, sample should be obtained in accordance with AASHTO T 168 and reduced to testing size.

The sample shall be brought to the compaction temperature range by careful, uniform heating in an oven immediately prior to molding.

08 **Slab Specimens** - Compact using a Linear Kneading Compactor (or equivalent) to an air void content of 7.0 ±2.0%. Specimens shall be 320 mm (12.5 inch) long and 260 mm (10.25 inch) wide. Thickness of 38 mm (1.5 inch) to 100 mm (4 inch) can be used and shall be at least twice the nominal maximum aggregate size.

09 **Superpave Gyratory Compactor Specimens -** Compact in accordance with the FOP for AASHTO T 312 to the air void content of 7 ±2.0%. Thickness (height) of 38 mm (1.5 inch) to 100 mm (4 inch) can be used and shall be at least twice the nominal maximum aggregate size.

- After compacting, remove specimens from the molds and cool at room temperature on a flat clean surface.

10 **Field Compacted (Core/Slab) Specimen –** Wet saw-cut compacted specimens taken from HMA pavements. Cores shall be 250 mm (10 inch); slabs shall be approximately 260 mm (10.25 inch) wide and 320 mm (12.5 inch) long. Slab thickness of 38 mm (1.5 inch) to 100 mm (4 inch) may be used. A height of 38 mm (1.5 inch) is typically used, but the core or slab may be wet saw-cut to adjust the height to fit the specimen mounting system.

Note 2: The sample should be loaded such that it is level to the surface of the mold. It must be trimmed if it is too tall or shimmed if it is too short. The down pressure of the wheel is calibrated at the center, level to the top of the mold. Even a small change in elevation will change the down pressure significantly.

Note 3: Dimensions of Field Compacted Specimens are subject to the dimensions of the mold. A different size may be necessary for proper mounting, i.e. 305mm (12 inch) cores may be more appropriate for some agencies/equipment.

11

- Determine the bulk specific gravity (G_{mb}) of each of the compacted specimens in accordance with Method "A" of the FOP for AASHTO T 166.
- Determine maximum specific gravity (G_{mm}) of the mix on a companion sample. FOP for AASHTO T 209.

12

- Calculate the air void content in percent (P_a) for each specimen, using the formula at the left. The target air void content for laboratory-compacted specimens is 7.0 ±2.0%. Field-compacted specimens are tested at the air void content at which they are obtained.

$$P_a = 100\left(1 - \frac{G_{mb}}{G_{mm}}\right)$$

where:

P_a = Percentage of air voids (nearest 0.1%)
G_{mm} = maximum specific gravity (T 209)
G_{mb} = Bulk specific gravity (T 166)

Calculation Example 13

Percentage Air Voids

$$P_a = 100\left(1 - \frac{2.363}{2.552}\right) = 7.41\text{, say } 7.4\%$$

where:

G_{mb} = 2.363
G_{mm} = 2.552

14 **Specimen Mounting –** Using Plaster-of-Paris at approximately a 1:1 ratio of plaster to water, rigidly mount the specimen in the mounting tray. The height of plaster should be equal to the height of the specimen to fill air space between the specimen and the tray. The plaster layer underneath the specimen shall not exceed 2 mm (0.08 inch). Allow the plaster to set for at least one hour.

15 **Test Temperature –** Based on the applicable specifications.

16 ## Procedure

1. Close drain valve.
2. Place mounted specimens and spacers in the wheel-tracker device.
3. Fill the device with hot water until the float device floats to the horizontal position. Adjust water temperature as necessary.

17 4. Bring to test temperature and hold for 30 minutes.

18 5. Lower the wheels onto the specimen.

19 6. Ensure the micro-control unit's LVDT readout reads between 10 mm (0.4 inch) and 18 mm (0.7 inch) this will be subtracted from the total displacement on the screen readout.

Note 4: To adjust the LVDT height, loosen the two screws on the LVDT mount and slide the LVDT up or down to the desired height. Tighten the screws.

Note 5: If the LVDT is mounted such that starting between 10 mm (0.4 inch) and 18 mm (0.7 inch) is not applicable, follow manufacturer's instructions.

20 7. Start the test.

21 The wheel-tracking device will shut off at 20,000 passes or when the average LVDT displacement (read from the micro-control unit, not the screen) is 40.90 mm (1.6 inch) or greater for an individual specimen.

Note 6: The wheel-tracking device may be programmed to a maximum allowed deformation. If the maximum allowed deformation is reached before 20,000 passes, the wheel will lift off the failed sample but continue testing the second sample.

22 8. Turn off machine and main power supply.

9. Open the valves beneath the tanks to drain the baths.

10. Raise the wheels and remove the specimens
23 and spacers.
11. Clean the water bath, heating coils, wheels, and temperature probe with water and scouring pads (or as per manufacturer's recommendation).
12. 24 Use a wet-dry vacuum to remove particles that have settled to the bottom.
13. Clean the filter elements and spacers.
14. Turn the wheels after each test so that the same section of the wheel is not in contact with the test specimen from test to test.

25 Calculations

Results of the wheel-tracker tests are plotted on a graph displaying rut depth (typically in millimeters) versus the number of passes for each test. A line is plotted for the left wheel, the right wheel, and an average of both wheels.

An examination of the graph can reveal the number of passes to failure, the maximum rut depth occurring, and a stripping inflection
26 point.

When using appropriate software, data may be manipulated in several ways including a regression report, a wheel-tracking report, and a wheel-tracking test**.**

27 The **regression report** is a plot of the creep slope, the stripping slope, and the resulting stripping inflection point (SIP). This is a useful
28 report for evaluating failed specimens. Use of the report requires the operator to examine the graph and select two points that represent a linear creep slope and two points that represent a linear stripping slope. The software will then plot both lines and give an SIP and the number of passes to the point (see figure 1). The report can be used to evaluate when stripping of a sample occurs.

The **wheel-tracking test** simply plots the passes versus the rutting depth for the left wheel, the right wheel and the average. This is the same graph produced by the wheel-tracking report without all the other report information. Use this report as a quick view of the test results.

The information can also be analyzed without software, see AASHTO T 324 for Stripping Inflection Point (SIP) calculation.

29

Report

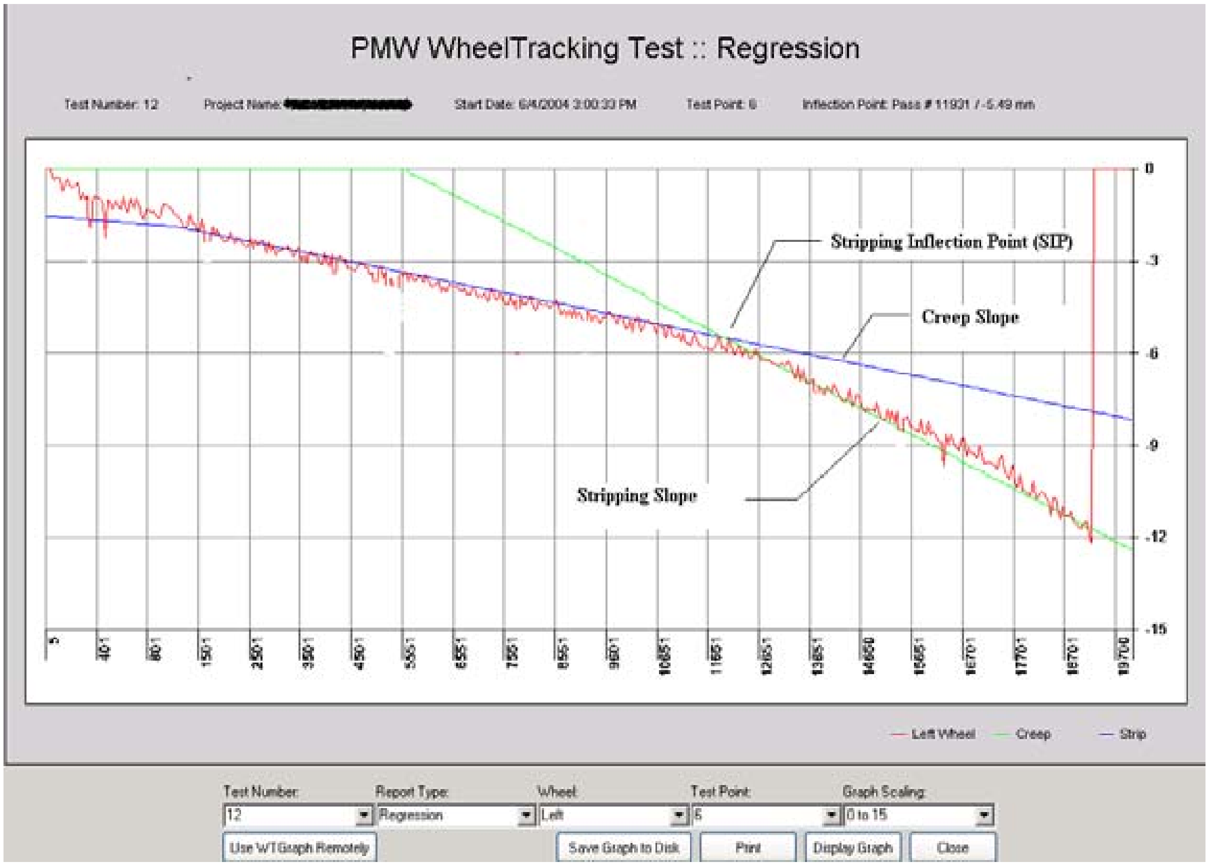
- HMA Production (Plant or Lab)
- Specimen production
    - Field: Slab or Core
    - Lab: Slab or SGC specimen
- Number of passes at maximum impression
- Maximum impression
- 30 Test temperature
- Specimen(s) air voids
- Creep slope
- Strip slope
- Stripping inflection point (SIP)

31

Tips!

- Check agency guidelines on correct test temperature.
- Check the correct setting of the LVDT readout.
- Follow all manufacturers' instructions.

Example Regression Graph (Figure 1)



REVIEW QUESTIONS

1. How many test specimens are prepared for each test?

2. What are the different types of specimens?

3. List the main steps of the procedure.

4. What does SIP stand for?

M 325

STANDARD SPECIFICATION FOR STONE MATRIX ASPHALT (SMA)
FOP FOR AASHTO M 325

M 325

STANDARD SPECIFICATION FOR STONE MATRIX ASPHALT (SMA)

FOP FOR AASHTO M 325

STANDARD SPECIFICATION FOR STONE MATRIX ASPHALT (SMA) FOP FOR AASHTO M 325

02

Scope

This FOP covers the design of Stone Matrix Asphalt (SMA) using the Superpave Gyratory Compactor (SGC). The SMA design is based on volumetric properties of the SMA in terms of air voids (V_a), voids in mineral aggregate (VMA), and the presence of stone-on-stone contact.

This standard specifies minimum quality requirements governing binder, aggregate, mineral filler, stabilizing additives, and mixture specifications for SMA mix designs.

03

Terminology

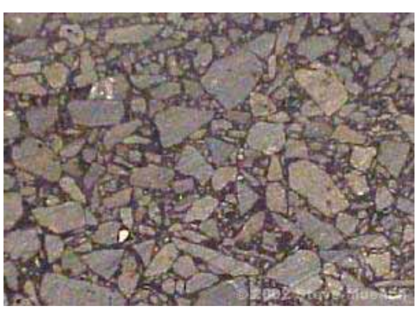
- **Air Voids (V_a)**
  The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture.
- **SMA Mortar**
  A mixture of asphalt binder, filler (material passing the No. 200 sieve), and stabilizing additive.

04

- **Stabilizing Additive**
  Either cellulose or mineral fiber.
- **Stone Matrix Asphalt (SMA)**
  A Hot-Mix Asphalt (HMA) mixture consisting of a coarse aggregate skeleton with stone-on-stone contact, and a rich asphalt binder mortar.

05

- **Stone-on-Stone Contact**
  The point where the VCA of the compacted mixture is less than the VCA of the dry-rodded coarse aggregate.



SMA
Stone-On-Stone Contact

06
- **Voids in the Coarse Aggregate (VCA)**
  Volume of voids between coarse aggregate particles in the combined grading.
- **Voids in the Mineral Aggregate (VMA)**
  The volume of the intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective binder content, expressed as a percent of the total volume of the specimen.

07

Significance and Use

- AASHTO M 325 may be used for designing and evaluating material and mixture properties for SMA.

08

Binder Requirements

The binder shall meet the following:

- Performance-graded
- Meet requirements of AASHTO M 320
- Appropriate for climate and traffic loading
- Or as specified by the contract documents

Guidance for selection of the appropriate binder is provided in the FOP for AASHTO M 323.

09

Aggregate Requirements

- Coarse Aggregate:
  Coarse aggregates shall be 100 percent crushed and conform to the quality requirements of Table 1.
- Fine Aggregate:
  Fine aggregates shall be 100 percent crushed and conform to the quality requirements of Table 2.

Table 1 10, 11

Coarse Aggregate Quality Requirements

Test	Method	Minimum	Maximum
Los Angeles (L.A.) Abrasion, percent loss	T 96	N/A	30 [a]
Flat and Elongated, percent [b]	D 4791		
3 to 1 ratio		N/A	20
5 to 1 ratio		N/A	5
Absorption, percent	T 85	N/A	2.0
Soundness (5 Cycles), percent [c]	T 104		
Sodium Sulfate, or		N/A	15
Magnesium Sulfate		N/A	20
Crushed Content, percent	D 5821		
One Face		100	N/A
Two Face		90	N/A

[a] Aggregates with higher L.A. Abrasion values have been used successfully to produce SMA mixes. However, when the abrasion exceeds 30, excessive breakdown may occur in the laboratory compaction process or during in-place compaction.

[b] Flat and Elongated criteria apply to the design aggregate blend.

[c] Sodium or magnesium sulfate may be used. It is not required to perform both methods.

Table 2 12

Fine Aggregate Quality Requirements

Test	Method	Minimum	Maximum
Soundness (5 Cycles), percent [a]	T 104		
Sodium Sulfate, or		N/A	15
Magnesium Sulfate		N/A	20
Liquid Limit, percent	T 89	N/A	25
Plasticity Index, percent	T 90	Non-plastic	

[a] Sodium or magnesium sulfate may be used. It is not required to perform both methods.

13

Note 1: It is recommended that mineral fillers with modified Rigden voids (IS 127) higher than 50 percent not be used in SMA. Experience has shown that such fillers excessively stiffen the SMA mortar.

Mineral Filler

- Consisting of finely divided mineral matter such as crusher fines and fly ash.
- Sufficiently dry to flow freely and essentially free of agglomerations.
- Free from organic impurities and having a plasticity index not greater than four.

14 Stabilizing Additive

- A stabilizer such as cellulose or mineral fiber will be added to the mixture to prevent excessive draindown. To maximize durability (through binder volume), fibers may be added regardless of draindown.
- Maximum draindown performed according to the FOP for AASHTO T 305 shall not exceed 0.3 percent by weight of the mix when held at the plant temperature for one hour.
- Cellulose dosage rate: Approximately 0.3 percent or more by total mixture mass and sufficient to prevent draindown.
- Mineral fiber dosage rate: Approximately 0.4 percent by total mixture mass and sufficient to prevent draindown.

Note 2: If the draindown from plant-produced samples exceeds that of laboratory-prepared samples the quantity of the stabilizer should be increased.

SMA Design Requirements

15 Combined Aggregate Requirements

- The combined aggregates shall conform to the requirements of Table 3.
- When the oven-dry bulk specific gravities, G_{sb}(OD), of the different materials to be used in the mixture vary by more than 0.2, the trial blend gradation shall be based on volumetric percentage.

Table 3

SMA Specification Gradation Bands 16

Sieve Size, in. (mm)	Nominal Maximum Aggregate Size					
	3/4" (19 mm)		1/2" (12.5 mm)		3/8" (9.5 mm)	
	Lower	Upper	Lower	Upper	Lower	Upper
1 (25)	100	---	---	---	---	---
3/4 (19)	90	100	100	---	---	---
1/2 (12.5)	50	88	90	100	100	---
3/8 (9.5)	25	60	50	80	70	95
No. 4 (4.75)	20	28	20	35	30	50
No. 8 (2.36)	16	24	16	24	20	30
No. 16 (1.18)	---	---	---	---	---	21
No. 30 (0.60)	---	---	---	---	---	18
No. 50 (0.30)	---	---	---	---	---	15
No. 200 (0.075)	8.0	11.0	8.0	11.0	8.0	12.0

17 **SMA Mixture Design Requirements**.

- The designed SMA mixture shall meet the requirements of Table 4.
- Determine Tensile Strength Ratio (TSR) of the SMA mixture according to the FOP for T 283 at 6.0 ± 1.0 percent air voids. Compact specimens according to the FOP for T 312.
- Draindown sensitivity shall be determined on the SMA mixture according to the FOP for T 305.

Table 4 18

SMA Mixture Specifications for Superpave Gyratory Compactor [a]

Property	Requirement
Air Voids, percent	4.0 (Note 3)
VMA, percent	17.0 minimum
VCA_{MIX}	Less than VCA_{DRC} (Note 4)
TSR	0.80 minimum
Draindown at Production Temperature, percent	0.3 maximum
Asphalt Binder Content, percent	6.0 minimum (Note 5)

[a] SMA Mixture Specification refers to specimens compacted in accordance with T 312 at 100 gyrations. When aggregates have an abrasion loss greater than 30 percent, the desirable number of SGC design gyrations is 75.

19

Note 3: For low-traffic volume roadways or colder climates, target air void contents less than 4.0 percent can be used, but should not be less than 3.0 percent.

Note 4: See R 46 for instructions on calculating VCA_{MIX} and VCA_{DRC}.

Note 5: Binder contents should be from 6.0 to 7.0 percent. Lowering the binder content below 6.0 percent may be detrimental to the SMA durability. Refer to guidance given on this issue in the FOP for R 46 when an SMA mixture cannot be designed within the minimum binder limits of Table 4.

REVIEW QUESTIONS

1. With what specification must the binder comply?

2. What are the binder requirements for use in SMA mix design?

3. What tests are performed for evaluation of compliance with coarse and fine aggregate requirements? How does this differ from those for standard Superpave mixes as described in M 323?

4. Describe requirements for mineral filler.

5. Why are stabilizing additives used? What approximate dosage rates are specified for the types noted in the FOP?

6. What is the maximum draindown permitted according to the FOP? What AASHTO test method is used for determining draindown characteristics?

7. When is it required to calculate combined aggregate grading based on volume rather than mass?

8. How do TSR requirements differ from those specified for standard Superpave mixes?

9. Describe requirements for target air void content. How does this differ from that specified for standard Superpave mixes?

10. How many gyrations of the SGC are required for an SMA design? How does this differ from that specified for standard Superpave mixes?

R 46

STANDARD PRACTICE FOR DESIGNING STONE MATRIX ASPHALT (SMA)

FOP FOR AASHTO R 46

R 46

STANDARD PRACTICE FOR DESIGNING STONE MATRIX ASPHALT (SMA)

FOP FOR AASHTO R 46

STANDARD PRACTICE FOR DESIGNING STONE MATRIX ASPHALT (SMA)

FOP FOR AASHTO R 46

Superpave Gyratory Compactor (SGC)

02
Scope and Significance

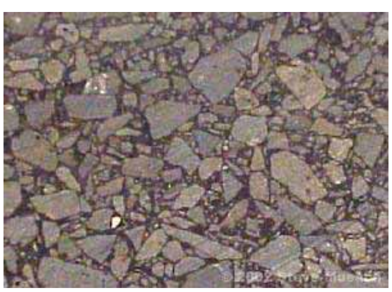
This FOP covers the design of Stone Matrix Asphalt (SMA). During the mix design process, aggregates and SMA mortar are combined to produce a mix formula based on volumetric properties in terms of air voids (V_a), voids in mineral aggregate (VMA), and the presence of stone-on-stone contact.

03 The Superpave Gyratory Compactor (SGC) is the method of compaction for fabricating specimens for the mix design process.

04
Terminology

- **G_{CA}** oven-dry bulk specific gravity (coarse aggregate fraction of combined grading).
- **P_{CA}** percent of coarse aggregate in the combined grading.
- **SMA Mortar**
  A mixture of asphalt binder, mineral filler, and stabilizing additive.
- **Stabilizing Additive**
  Either cellulose or mineral fiber.

05
- **Stone Matrix Asphalt (SMA)**
  A Hot-Mix Asphalt (HMA) mixture consisting of a coarse aggregate skeleton with stone-on-stone contact, and a rich asphalt binder mortar.



SMA
Stone-On-Stone Contact

06
- **Stone-on-Stone Contact**
  The point where the VCA of the compacted mixture is less than the VCA of the dry-rodded coarse aggregate.

07
- **VCA** Volume of voids between coarse aggregate particles in the combined grading.
- **VCA_{DRC}**
  Volume of voids between coarse aggregate particles in the combined gradation (dry-rodded condition).
- **VCA_{MIX}**
  Volume of voids between coarse aggregate particles of the compacted mixture (air voids, binder, fine aggregate, mineral filler,

and stabilizing additive).

08 Prerequisite Tests

- **AASHTO T 2 –** Sampling of Aggregates
- **AASHTO T 248 –** Reducing Samples of Aggregate to Testing Size
- **AASHTO T 11 –** Materials Finer than No. 200 Sieve in Mineral Aggregate by Washing
- **AASHTO T 27 –** Sieve Analysis of Fine and Coarse Aggregates
- **AASHTO T 84 and T 85 –** Specific Gravity and Absorption of Fine and Coarse Aggregates
- 09 **AASHTO T 19 –** Bulk Density (“Unit Weight”) and Voids in Aggregate
- **AASHTO T 89 and T 90 –** Liquid Limit, Plastic Limit and Plasticity Index
- **AASHTO T 96 –** Los Angeles Abrasion of Coarse Aggregate
- 10 **AASHTO T 104 –** Soundness of Coarse and Fine Aggregates
- **ASTM D 4791 –** Flat Particles, Elongated Particles, or Flat & Elongated Particles in Coarse Aggregate
- **ASTM D 5821 –** Determining the Percentage of Fractured Particles in Coarse Aggregate

11 Mix Design Overview

The major steps that must be conducted for successful completion of the SMA mix design process are:

- **Material Selection:** Select materials that meet specified requirements.
  - Aggregates, Binder, Mineral Filler and Stabilizing Additives.
- **Optimum Gradation Selection:** Produce three or more trial aggregate gradations.
- **Optimum Binder Content Selection:** Using the optimum gradation, produce specimens at a minimum of three varying binder contents.
- 12 **Evaluate Draindown:** Test mixture according to the FOP for T 305.
- **Evaluate Moisture Susceptibility:** Compact according to the FOP for T 312, test according to the FOP for T 283.
- **Evaluate Final Mix Properties:** Verify compliance with M 325. Final mixture must

meet all specified parameters.

13 Material Selection

Select materials meeting the provisions of AASHTO M 325 including the following. (Refer to M 325 for a more detailed description of required material properties).

- **Aggregates:** 100 percent crushed, meeting the specified requirements for L.A. Abrasion, Soundness, Flat and Elongated Particles, Crushed Content, Absorption, Liquid Limit, and Plasticity Index.
- **Binder:** Performance-graded meeting the requirements of M 320, appropriate for climate and traffic loading of the project.
- 14 **Mineral Filler:** Finely divided mineral matter such as crusher fines and fly ash.
- **Stabilizing Additive:** Stabilizer such as cellulose or mineral fiber to prevent excessive draindown, used at the appropriate dosage rate.

15 Optimum Gradation Selection

1. Perform prerequisite procedures / tests
2. Establish trial blend grading
3. Establish trial binder content
4. Mix and compact trial blend specimens
5. Evaluate compacted trial mixtures
6. Select optimum aggregate grading

16 Prerequisite Procedures / Tests

- Obtain the specific gravity of mineral filler (AASHTO T 100).
- Obtain appropriate samples of each material to be used in the SMA design.
- Perform G_{sb}(OD) Specific Gravity and Absorption tests for each aggregate. G_{sb}(SSD) and G_{sa} specific gravities are not required.
- Perform Sieve Analysis on each aggregate. Verify that grading of samples obtained for
  17 mix design is representative of the average stockpile grading for each product.
- Separate aggregates into required size fractions. Recommended size fractions are

presented in Table 1.

Table 1 – Aggregate Size Fractions 18

Passing		Retained	
1½”	(37.5 mm)	1”	(25 mm)
1”	(25 mm)	3/4”	(19 mm)
3/4”	(19 mm)	1/2”	(12.5 mm)
1/2”	(12.5 mm)	3/8”	(9.5 mm)
3/8”	(9.5 mm)	No. 4	(4.75 mm)
No. 4	(4.75 mm)	No. 8	(2.36 mm)
No. 8	(2.36 mm)	No. 200	(0.075 mm)
Passing No. 200 (0.075 mm)			

19 Establish Trial Blend Grading

Specifications for aggregate gradation are given in M 325 as upper and lower limits on certain sieve sizes. Within these upper and lower limits, numerous aggregate gradations can be fabricated.

20 Number and Types of Samples

- Select a minimum of 3 trial blends.
- Calculate combined aggregate grading for each trial blend (See Note 1).

  It is recommended that one grading fall along the coarse limits, one along the fine limits, and one near the center of the grading bands contained in the FOP for M 325.
- Calculate the combined G_{sb}(OD) of each blend (See FOP for AASHTO R 35).
- For each trial blend, a minimum of two samples must be prepared for compaction by the SGC.
- 21 Replicate samples must also be produced for theoretical maximum specific gravity for each of the trial blends.
- For each trial blend, prepare a sufficient quantity of material for determination of G_{CA} and VCA_{DRC} (See Note 2).
- Determine the G_{CA} of the coarse aggregate fraction of each trial blend (FOP for T 85).

Note 1: If the oven-dry bulk specific gravities of the different aggregates, including mineral filler, vary by more than 0.2 the combined grading should be calculated based on volume rather than mass.

Note 2: Quantity of material that must be prepared will be determined by the measure size required by T 19 for the nominal maximum aggregate size. The coarse aggregate (stone) fraction is that portion retained on the No. 4 (4.75mm) sieve for 3/4” (19mm) and 1/2” (12.5mm) mixtures. For 3/8” (9.5mm) mixtures it is the portion retained on the No. 8 (2.36mm) sieve.

- Determine the dry-rodded VCA of the coarse aggregate fraction of each trial blend by compacting the aggregate according to the dry-rodded method of the FOP for AASHTO T 19. Calculate VCA_{DRC} according to the formula presented below.

$$VCA_{DRC} = \frac{(G_{CA} \times \gamma_w) - \gamma_s}{(G_{CA} \times \gamma_w)} \times 100$$ 22

where:

VCA_{DRC}	=	volume of voids between coarse aggregate particles in the combined aggregate gradation, dry-rodded condition (percent)
G_{CA}	=	oven-dry bulk specific gravity of the coarse aggregate fraction of the aggregate blend tested according to the FOP for T 85
γ_s	=	unit weight of the coarse aggregate fraction of the aggregate blend, compacted according to the dry-rodded method of T 19 (lb/ft^3)
γ_w	=	unit weight of water (assumed to be 62.4 lb/ft^3)

23 **Preparing Aggregate Blend Gradations**

- If the specific gravities of the different aggregate components do not vary by more than 0.2, the combined grading for each trial blend may be calculated by mass as presented in the FOP for AASHTO R 35.
- If the specific gravities of the different aggregate components vary by more than 0.2, calculate the combined grading for each trial blend by volume.

24 **Calculating Aggregate Blend Gradations by Volume**

If the combined grading must be calculated by volume, do so according to the following steps: (A calculation example is provided at the end of the FOP).

1. Record the individual percent retained on every sieve size for each of the aggregates, including the minus No. 200 fraction. The sum of these individual values should equal 100 for each aggregate.
2. Consider the individual percentages retained as grams retained, where the total sample mass for each aggregate would be 100 grams.

Note 3: Be sure to use the G_{sb}(OD) of the appropriate aggregate when calculating individual volumes for that aggregate.

25
3. Calculate the individual volume retained for every sieve size of each aggregate according to the following formula:

$$V = \frac{M}{D}$$ 26

where:

V = volume retained on each individual sieve, (cm^3)

M = mass retained on individual sieve, (grams)

D = density of individual aggregate, (grams/cm^3), calculated as the G_{sb}(OD) times the density of water (assumed to be 1 gram/cm^3). In effect, the G_{sb}(OD) may be considered the equivalent of density for this calculation (See Note 3 above)

27
4. Record the individual volume retained for every sieve size of each aggregate, including that of the minus No. 200 fraction.
5. Sum the individual volumes and record as the total volume of each product.
6. Calculate the individual volumes retained for each sieve size in the combined aggregate blend using the following formula:

$$IVR = (VRA \times a) + (VRB \times b) + (VRC \times c) + ...(VRN \times n)$$ 28

where:

IVR	=	**I**ndividual **V**olume **R**etained for each sieve of the combined aggregate blend (cm^3)
VRA, VRB, VRC,……VRN	=	**V**olume **R**etained on each sieve size of each individual product **A, B, C**……**N** (cm^3)
a, b, c,….. n	=	Percentage of individual aggregates A, B, C……N used for the blend, expressed in decimal form, totaling 1.00

29

7. Calculate the cumulative volume retained of the combined aggregate blend by summing the individual values calculated in step 6. This is the total volume of the blend, and will be used to calculate percent retained and passing by volume.
8. Calculate individual percent retained and percent passing for the blend. (See Note 4).
9. Record the combined percent passing and compare with the grading bands from M 325.

Note 4: The method of calculation is the same as used for a standard T 27 test, except that the units used for the calculation are volume (cm^3) rather than mass (grams).

30

Establish Trial Binder Content

- M 325 states that binder content should be in the range from 6.0 to 7.0 percent.
- Where no previous history is available, a starting binder content between 6.0 and 6.5 percent is recommended. This is appropriate for aggregates having G_{sb}(OD) in the "normal" range of 2.55 to 2.75.
- Adjustment to the trial binder content may be required depending on the G_{sb}(OD) of the aggregate. Table 2 provides information that will be helpful in making such adjustments. Additional trial specimens may be required to establish appropriate binder content.

Table 2 – Trial Binder Contents for Varying G_{sb}(OD) of Combined Aggregates 31

Combined Aggregate G_{sb}(OD)	Minimum Binder Content, %
2.40	6.8
2.45	6.7
2.50	6.6
2.55	6.5
2.60	6.3
2.65	6.2
2.70	6.1
2.75	6.0
2.80	5.9
2.85	5.8
2.90	5.7
2.95	5.6
3.00	5.5

32

Mix and Compact Trial Blend Specimens

Note 5: The temperatures determined for mixing and compaction are appropriate for neat asphalt binders. When using modified asphalt binders, consult the manufacturer's guidelines, or those of the agency, for mixing and compaction temperatures.

1. Determine mixing and compaction temperatures for the binder (See Note 5).

   Mixing temperature: Temperature to which the binder must be heated to produce a viscosity of 170 ± 20 cSt.

   Compaction temperature: Temperature to which the binder must be heated to produce a viscosity of 280 ± 30 cSt.

33

2. Prepare at least two replicate specimens at the initial trial binder content for each trial blend for compaction using the SGC.

Compacted SMA Specimen

Note 6: 4500 to 4700 grams of aggregate will usually be sufficient to compact specimens of 110 to 120 mm height. Trial specimens may be necessary.

3. Prepare replicate specimens for theoretical maximum specific gravity (G_{mm}) (FOP for AASHTO T 209).

34

4. Mix and condition the loose mix (FOP for AASHTO R 30).

Note 7: Compact specimens for 75 gyrations when the aggregate has a Los Angeles Abrasion loss greater than 30 percent.

5. Compact specimens for 100 gyrations (FOP for AASHTO T 312). (See Note 7)

35 Evaluate Compacted Trial Mixtures

- Determine G_{mb} of compacted specimens according to the FOP for T 166.
- Determine G_{mm} of replicate specimens according to the FOP for T 209.
- Calculate VMA according to the following formula:

$$VMA = 100 - \left(\frac{G_{mb}}{G_{sb(OD)}}\right)P_s \qquad 36$$

where:

VMA	=	Voids in the Mineral Aggregate, percent
G_{mb}	=	Bulk specific gravity of the compacted specimen
G_{sb}(OD)	=	Oven dry bulk specific gravity of the total aggregate
P_s	=	Percent of aggregate in the mixture

- Calculate VCA_{MIX} according to the following formula:

$$VCA_{MIX} = 100 - \left(\frac{G_{mb}}{G_{CA}}\right)P_{CA} \qquad 37$$

where:

VCA_{MIX}	=	Volume of voids between coarse aggregate particles of the compacted mixture (air voids, binder, fine aggregate, mineral filler, and stabilizing additive), percent
G_{mb}	=	Bulk specific gravity of the compacted specimen
G_{CA}	=	Oven dry bulk specific gravity of the coarse aggregate fraction
P_{CA}	=	Percent of coarse aggregate in the total mixture

- Calculate V_a according to the following formula:

$$V_a = 100 \times \left(1 - \left(\frac{G_{mb}}{G_{mm}}\right)\right)$$ 38

where:

V_a	=	Total air voids in the compacted mixture, percent
G_{mb}	=	Bulk specific gravity of the compacted specimen
G_{mm}	=	Theoretical maximum specific gravity of the mixture

39 Select Optimum Aggregate Grading

Using the data from evaluation of the trial blends described above, select the optimum aggregate grading based on the following criteria:

- Select the blend with the lowest percentage of coarse aggregate that meets or exceeds minimum VMA requirements, and where the VCA_{MIX} is less than VCA_{DRC} (See Note 8).

Note 8: The VMA of the optimum blend should be somewhat higher than the minimum to allow for reduction in VMA during plant production.

40 Selecting Optimum Binder Content

Using the optimum grading, the steps for selecting the optimum binder content are:

1. Select Binder Contents
2. Fabricate and Compact Specimens
3. Select Optimum Binder Content

41 Select Binder Contents

Select at least three binder contents that will provide results encompassing the specified air void content (V_a).

- Prepare replicate samples for compaction in the SGC at each of the three binder contents.
- Prepare replicate samples at each binder content for determination of Theoretical Maximum Specific Gravity.

42 **Fabricate and Compact Specimens**

- Mix and condition specimens (FOP for AASHTO R 30).
- Compact replicate specimens according to the FOP for AASHTO T 312.
  1. A minimum of 2 specimens at each of the 3 binder contents.
  2. Compact the replicate specimens to 100 or 75 gyrations depending on L. A. Abrasion loss (See Note 7).

43 **Select Optimum Design Binder Content**

- Determine the binder content to the nearest 0.1 percent that corresponds with the specified air void requirement of the FOP for M 325, by graphical or mathematical interpolation.
- Verify that minimum VMA requirements are met, and that VCA_{MIX} is less than VCA_{DRC}.
- This is the Optimum Design Binder Content.

44 **Evaluate Draindown**

Evaluate draindown of the mixture at optimum binder content according to the FOP for AASHTO T 305.

45 **Evaluate Moisture Susceptibility**

Compact samples according to the FOP for AASHTO T 312 at V_a of 6.0 ± 1%.

Evaluate moisture susceptibility at optimum binder content by testing in accordance with the FOP for AASHTO T 283.

46 **Evaluate Final Mix Properties**

Compare final mixture properties with the requirements of AASHTO M 325 and those of the agency prior to submitting report.

Adjusting the Mixture to Meet Properties

47 1. **Adjusting V_a.** V_a may be adjusted by raising or lowering the binder content. Binder content lower than the minimum required by M 325 should be avoided. If binder content less than the minimum specified by M 325 would be required to increase V_a to an acceptable level, the VMA should be increased instead. (See Note 9).

Note 9: When aggregate specific gravity is outside the "normal" range, it may be appropriate to use a binder content not in compliance with requirements of M 325. Refer to Table 2 for guidance in selecting an appropriate binder content under these circumstances.

48 2. **Adjusting VMA.** An increase in VMA is usually obtained by raising the percentage of coarse aggregate in the blend. Under some circumstances, it may be required to select aggregate from another source.

49 3. **Adjusting VCA_{MIX}.** The VCA_{MIX} must be lower than VCA_{DRC}. When the reverse is true, the aggregate grading must be changed. This is usually accomplished by increasing the coarse aggregate content of the blend.

50 4. **Adjusting Draindown.** When draindown fails, increase the amount of, or select a different stabilizing additive.

5. **Adjusting Moisture Susceptibility.** If the requirement for moisture susceptibility is not met, increased Tensile Strength Ratio (TSR) may be achieved by adding anti-strip agents or by selecting aggregate and binder sources having better compatibility.

51 **Report**

Project name and number
Mix design number
Design aggregate structure
- Source of aggregate
- Type of aggregate

Type and amount of stabilizing additive
Design binder source and grade
52 Optimum gradation and binder content
Volumetric properties of trial blends
Volumetric properties at optimum binder content
Draindown results
Moisture susceptibility results

53 **Tips!**

- Stone-on-Stone contact is defined as the condition where VCA_{MIX} is less than VCA_{DRC}
- It may be required to calculate combined aggregate grading based on volume rather than mass, depending on the difference between the G_{sb}(OD) of the aggregates
- Final binder content should not be lower than 54 the minimum specified in AASHTO M 325. If lower binder content would be necessary to achieve proper air voids, then the VMA should be increased instead
- Compare final mixture properties with M 325 requirements prior to submitting report

Calculation Example (Aggregate Grading by Volume, 3/4" Mix) 55

Step-by-step instructions with calculation examples are presented for the gradation by volume procedure.

Table 3 illustrates individual aggregate properties for percent passing, G_{sb}(OD), and absorption.

Table 3 – Individual Product Properties 56				
Sieve Size	**Identification and Grading (Percent Passing)**			
	Agg. A	**Agg. B**	**Agg. C**	**Min. Filler**
1"	100.0	100.0	100.0	100.0
3/4"	100.0	100.0	100.0	100.0
1/2"	65.8	71.2	97.4	100.0
3/8"	42.6	46.4	84.6	100.0
No. 4	9.3	6.0	48.9	100.0
No. 8	4.6	4.2	27.8	100.0
No. 16	2.6	3.7	16.6	100.0
No. 30	2.4	2.9	10.7	100.0
No. 50	2.1	2.6	7.6	100.0
No. 100	1.4	1.8	5.4	89.7
No. 200	1.2	1.7	4.6	72.5
Specific Gravity and Absorption				
G_{sb}(OD)	2.616	2.734	2.736	2.401
Absorption	1.20	0.50	0.50	1.00

Steps for Calculating Gradation by Volume (Data shown for No. 8 Sieve) 57

1- Calculate or record the individual percent retained for every sieve of each product used. (The individual percentages, including the portion passing the No. 200 sieve, should equal 100.0).

If calculating the individual percent retained from the cumulative percent passing, subtract the percent passing on the target sieve from the percent passing of the next larger sieve. Perform this operation for each sieve size in each product and record the data.

Using the gradings shown in Table 3, the individual percent retained on the No. 8 sieve for the four products used would be as follows:

Agg. A: 9.3 – 4.6 = 4.7

Agg. B: 6.0 – 4.2 = 1.8

Agg. C: 48.9 – 27.8 = 21.1

Min. Filler: 100.0 – 100.0 = 0.0

The data for all sieves of each material are illustrated in Table 4.

Table 4 – Product Grading (Individual Percent Retained) 58

Sieve Size	Identification and Grading			
	Agg. A	Agg. B	Agg. C	Min. Filler
1”	0.0	0.0	0.0	0.0
3/4"	0.0	0.0	0.0	0.0
1/2"	34.2	28.8	2.6	0.0
3/8”	23.2	24.8	12.8	0.0
No. 4	33.3	40.4	35.7	0.0
No. 8	4.7	1.8	21.1	0.0
No. 16	2.0	0.5	11.2	0.0
No. 30	0.2	0.8	5.9	0.0
No. 50	0.3	0.3	3.1	0.0
No. 100	0.7	0.8	2.2	10.3
No. 200	0.2	0.1	0.8	17.2
– No. 200	1.2	1.7	4.6	72.5
Total	100.0	100.0	100.0	100.0

59

2- Consider these individual percentages retained as being grams rather than percentages, where each product totals 100 grams. Using the data from Table 4, the individual grams retained for the four products would be the same values as those of the percentages calculated in step 1 above.

60

3- Calculate the individual volume retained for every individual sieve size of each product by dividing the individual grams retained by the density of the respective products, where density of a given individual product equals G_{sb}(OD) times the density of water (water density is assumed to be 1 gram/cm^3).

Using the formula from page 9-6, the G_{sb}(OD) values from Table 3, and the individual masses retained from Table 4, the following volumes are obtained for the No. 8 sieve:

Formula for Volume calculation (cm³): $V = \frac{M}{D}$

Agg. A: $$V = \frac{4.7\ \text{g}}{2.616\ \text{g/cm}^3} = 1.80\ \text{cm}^3$$

Agg. B: $$V = \frac{1.8\ \text{g}}{2.734\ \text{g/cm}^3} = 0.66\ \text{cm}^3$$

Agg. C: $$V = \frac{21.1\ \text{g}}{2.736\ \text{g/cm}^3} = 7.71\ \text{cm}^3$$

Min. Filler: $$V = \frac{0.0\ \text{g}}{2.401\ \text{g/cm}^3} = 0.00\ \text{cm}^3$$

Record the data thus calculated (See Table 5 for examples)

Table 5 – Product Volumes (Individual Volume Retained) 61

Sieve Size	Identification and Volume (cm³)			
	Agg. A	Agg. B	Agg. C	Min. Filler
1”	0.00	0.00	0.00	0.00
3/4"	0.00	0.00	0.00	0.00
1/2"	13.07	10.53	0.95	0.00
3/8”	8.87	9.07	4.68	0.00
No. 4	12.73	14.78	13.05	0.00
No. 8	1.80	0.66	7.71	0.00
No. 16	0.76	0.18	4.09	0.00
No. 30	0.08	0.29	2.16	0.00
No. 50	0.11	0.11	1.13	0.00
No. 100	0.27	0.29	0.80	4.29
No. 200	0.08	0.04	0.29	7.16
– No. 200	0.46	0.62	1.68	30.20
Total Volume	38.23	36.57	36.54	41.65

62

4- Calculate the combined volume retained for each individual sieve size using the individual volumes retained from Step 3 and the percent utilization of the various products expressed in decimal form.

63

Using data from Tables 5 and 6, the following example is shown for the No. 8 sieve.

Product utilization (from Table 6) is as follows: Agg. A, 40%; Agg. B, 41%; Agg. C, 10%; Min. Filler, 9% (These percentages, expressed as decimals, are 0.40, 0.41, 0.10, and 0.09 respectively. Note that the decimal equivalents total 1.00).

The individual contribution from each product is shown below for the No. 8 sieve:

Agg. A: $1.80\,\text{cm}^3 \times 0.40 = 0.72\,\text{cm}^3$

Agg. B: $0.66\,\text{cm}^3 \times 0.41 = 0.27\,\text{cm}^3$

Agg. C: $7.71\,\text{cm}^3 \times 0.10 = 0.77\,\text{cm}^3$

Min. Filler: $0.00\,\text{cm}^3 \times 0.09 = 0.00\,\text{cm}^3$

64

Using the formula from page 9-7, the combined Individual Volume Retained (IVR) for the No. 8 sieve is shown below. Table 6 summarizes the data thus calculated for all sieves in the combined grading.

$$\text{IVR} = (1.80 \times 0.40) + (0.66 \times 0.41) + (7.71 \times 0.10) + (0.00 \times 0.09) = 1.76\,\text{cm}^3$$

Table 6 – Trial Blend Grading by Volume 65

Sieve Size	Volume Retained by Product (cm^3)				Combined Grading		
	Agg. A (40%)	Agg. B (41%)	Agg. C (10%)	Min. Filler (9%)	Individ. Volume Retained (cm^3)	Individ. Percent Retained	Percent Passing
1”	0.00	0.00	0.00	0.00	0.00	0.0	100.0
3/4"	0.00	0.00	0.00	0.00	0.00	0.0	100.0
1/2"	5.23	4.32	0.10	0.00	9.65	25.6	74.4
3/8”	3.55	3.72	0.47	0.00	7.74	20.5	53.9
No. 4	5.09	6.06	1.30	0.00	12.45	33.0	20.9
No. 8	0.72	0.27	0.77	0.00	1.76	4.7	16.2
No. 16	0.30	0.07	0.41	0.00	0.78	2.1	14.1
No. 30	0.03	0.12	0.22	0.00	0.37	1.0	13.1
No. 50	0.04	0.05	0.11	0.00	0.20	0.5	12.6
No. 100	0.11	0.12	0.08	0.39	0.70	1.9	10.7
No. 200	0.03	0.02	0.03	0.64	0.72	1.9	8.8
– No. 200	0.18	0.25	0.17	2.72	3.32	-----	-----
				Total Volume	37.69		

66

5- Sum the combined volumes calculated for all individual sieve sizes, including the fraction passing the No. 200 sieve. This is the total volume of the combined grading and will be used to calculate the individual percent retained by volume. (See Table 6 where total volume of the combined grading equals 37.69 cm^3).

Individual percent retained is calculated in the same fashion as for a conventional gradation, except that the units used for the calculation are in volume (cm^3) rather than mass (grams).

The following example illustrates the individual percent retained by volume for the No. 8 sieve.

$$\text{Individual Percent Retained} = \frac{1.76\ \text{cm}^3}{37.69\ \text{cm}^3} \times 100 = 4.7\ \text{percent}$$

67

Once individual percent retained is calculated for each sieve size, percent passing is calculated as for any other gradation. See Table 6 for combined grading on all sieves.

68

The difference between percent passing by volume and mass may or may not be substantially different, depending on how much the G_{sb}(OD) of the individual products varies. See Table 7 for a comparison of gradings calculated by mass and volume. In this table the gradation by mass failed to meet the requirement for the No. 8 sieve, and thus fails to meet M 325 grading requirements. The gradation by volume met all grading requirements.

Table 7 – Comparison of Gradings (Mass vs. Volume, 3/4" Mix) 69

Sieve Size	**Combined Trial Blend Grading (Percent Passing)**		
	Percent by Mass [a]	**Percent by Volume [b]**	**M 325 Specification**
1”	100.0	100.0	100
3/4"	100.0	100.0	90 – 100
1/2"	74.3	74.4	50 – 88
3/8”	53.5	53.9	25 – 60
No. 4	20.1	20.9	20 – 28
No. 8	15.3 [a]	16.2	16 – 24
No. 16	13.2	14.1	-----
No. 30	12.2	13.1	-----
No. 50	11.7	12.6	-----
No. 100	9.9	10.7	-----
No. 200	8.2	8.8	8 – 11

[a] Does not meet specification for No. 8 sieve

[b] Meets specification for all sieves

REVIEW QUESTIONS

1. Define Stone-on-Stone contact.

2. What is the difference between VCA_{DRC} and VCA_{MIX}?

3. How many trial blends are required? How are the trial gradations selected relative to the grading bands specified in M 325?

4. For a 3/8” (9.5 mm) mix, what size fraction is considered to be Coarse Aggregate?

5. How does one calculate the individual volume retained for a given sieve size of an aggregate product?

6. After selecting trial gradings and mixing & testing specimens, how is the optimum grading selected?

7. What criteria are used to select the optimum binder content?

8. Given the following, calculate the VCA_{MIX}.

   G_{mb} = 2.364 (Bulk Specific Gravity of Compacted Specimen)

   G_{CA} = 2.692 (Oven-Dry Bulk Specific Gravity of the Coarse Aggregate Fraction)

   P_{CA} = 78 percent (Percent Coarse Aggregate in the mixture)

9. If the VMA of the mixture is too low, how does one generally go about raising it to an acceptable level?

T 305

STANDARD METHOD OF TEST FOR DETERMINATION OF DRAINDOWN CHARACTERISTICS IN UNCOMPACTED ASPHALT MIXTURES

FOP FOR AASHTO T 305

T 305

STANDARD METHOD OF TEST FOR DETERMINATION OF DRAINDOWN CHARACTERISTICS IN UNCOMPACTED ASPHALT MIXTURES

FOP FOR AASHTO T 305

STANDARD METHOD OF TEST FOR DETERMINATION OF DRAINDOWN CHARACTERISTICS IN UNCOMPACTED ASPHALT MIXTURES
FOP FOR AASHTO T 305

02 ## Scope and Significance

This test method covers the determination of the amount of draindown of uncompacted asphalt mixture samples when held at elevated temperatures such as those used in plant production, storage, transport and placement. The test method may be used to determine compliance with specified draindown requirements.

03 The test is primarily used for mixtures with high coarse aggregate content such as open-graded friction courses and Stone Matrix Asphalt (SMA).

The test may be used to evaluate draindown characteristics during mixture design and/or plant production.

04 ## Definition

- **Draindown:** That portion of the material that separates itself from the sample during the test. It may consist of either binder or a combination of binder and fine aggregate.

05 ## Apparatus

- **Balance:** Of sufficient capacity for primary sample masses, accurate to 0.1 gram.
- **Forced Draft Oven:** Capable of maintaining temperature from 250 to 350 ±3.6ºF.
- **Plates:** Cake pans or pie tins of appropriate size and durability to withstand oven temperatures.

06
- **Standard Basket:** Cylindrical in shape, manufactured of 0.25-inch sieve cloth as specified in M 92. Nominal dimensions of 4.25-inch diameter, 6.5-inch height with the basket bottom 1-inch above the bottom of the assembly.
- **Miscellaneous Tools:** Gloves, trowels, mixer, bowls, etc.

Sample Preparation

07 **Laboratory-Prepared Samples:**

- Temperature: Determine draindown at expected plant production temperature and 27ºF above. (See Note 1)
- Number of Samples: Duplicate samples for each temperature tested.
- 08 Preparation Steps:
  1. Dry aggregate to constant mass, cool, and separate into appropriate size fractions.
  2. Determine anticipated plant production temperature or laboratory mixing temperature (whichever is specified to be used).
  3. Combine aggregates according to the job-mix formula (JMF) grading sufficient to produce 1200 ± 200 grams of completed mixture for each sample.
  4. 09 Place aggregate samples in the oven and heat to a temperature not exceeding the mixing temperature from step 2 by more than 50ºF.
  5. Heat asphalt cement to the temperature established in step 2.
  6. Place heated mixing bowl on the balance and zero the balance.
  7. 10 Place heated aggregates in the mixing bowl. Add any stabilizers and mix thoroughly, forming a crater in the aggregate blend. Determine and record mass of material. (See Note 2)
  8. Add the required mass of binder to result in the JMF binder content. (At this point, temperature of the aggregate and binder shall be within the required mixing temperature range).
  9. 11 Mix quickly by mechanical means, or by hand, until the aggregate is thoroughly coated.

Note 1: When performing the test as part of mix design, two temperatures are selected to determine the effect of variation in plant production temperatures.

Note 2: Some stabilizers such as fibers or some polymers must be added to the aggregates prior to mixing with asphalt binder. Other types of stabilizers must be added to the asphalt binder prior to mixing with the aggregate.

10. Remove contents from the bowl, scrape bowl and mixing apparatus clean, and use the prepared material as described below under "Procedure."

12 **Plant-Produced Samples:**

- Number of samples: Duplicate samples should be tested at plant production temperature.
- Temperature: Conduct tests only at plant production temperature. A second, higher temperature is not required.
- 13 Sampling: Obtain during production at any appropriate location such as trucks prior to mixture leaving the plant. (See Note 3)
- Sample Reduction: Reduce to specified sample size according to the FOP for AASHTO R 47.

Note 3: To avoid occurrence of draindown prior to sampling, it may be preferable to obtain samples prior to storage in surge or storage bins.

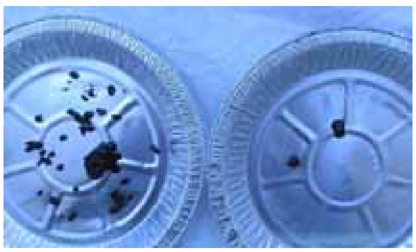
14 ## Procedure

1. Preheat the oven to the required test temperature.
2. Make all mass determinations to the nearest 0.1-gram.
3. Determine the mass of a clean, empty wire basket.
4. 15 Transfer the entire hot sample to the wire basket. After placing the material in the basket do not consolidate or otherwise disturb the sample. (See Note 4)
5. 16 Determine the mass of the filled basket.
6. 17 Subtract the mass determined in step 3 from the mass determined in step 5 and record as the mixed sample mass prior to draindown (M_t).
7. Determine and record the mass of a clean plate or other suitable container (M_i).

Note 4: Work quickly to avoid cooling of the sample. If the sample cools more than 45ºF below the required test temperature it is necessary to increase the test duration.

Weighing Filled Basket

Basket in Oven



Draindown Results

18 8. Place the basket on the plate and place the assembly in the oven at the required temperature for 1-hour ± 5 minutes. If the sample has cooled below the test

19 temperature by more than 45ºF, the test duration must be increased to 70 ± 5 minutes.

20 9. After the required test duration, remove the basket and plate assembly from the oven.

10. Remove the basket from the plate and determine the mass of the plate plus

21 drained material (M_f).

22 ## Calculation

- For each individual test, calculate the percent of the mixture that drained according to the formula presented below.
- Average the duplicate results from each test temperature for the report.

$$\% \text{ Draindown} = \frac{M_f - M_i}{M_t} \times 100$$ 23

where:

M_t = Mass of mixture prior to draindown

M_i = Mass of clean plate prior to draindown

M_f = Mass of plate and contents after draindown

24 ## Report

- Report on standard forms approved by the agency
- Identify whether samples were laboratory-produced or plant-produced
- Test temperature
- Test duration
- Report the average percent drainage at each test temperature as required by the agency
- Other information as required by the agency

Tips! 25

- Laboratory-mixed samples must be tested at two temperatures; plant-produced samples at only the plant production temperature
- Do not compact or otherwise disturb the sample after installing in the basket
- Base test duration on the temperature of the sample after mixing
- Remember to report the average draindown of the duplicate samples as required by the agency

REVIEW QUESTIONS

1. What is the purpose of this procedure? The procedure applies primarily to what types of mixtures?

2. Describe the basket assembly used for this test.

3. How many specimens are tested? At what temperature(s) are they tested?

4. Briefly describe the aggregate preparation steps.

5. Describe the mass of the aggregate prior to mixing with asphalt binder.

(Next Page)

6. How long do samples remain in the oven?

7. How are test results reported?

Section 988

GUIDELINES FOR LABORATORY MIXING OF HMA

988.01 Scope

This procedure provides guidelines for laboratory mixing of Hot Mix Asphalt for use in volumetric mix designs, Hamburg Wheel-Track Testing and any other testing performed on laboratory mixed HMA.

REFERENCES:

AASHTO STANDARDS:

R 30 Standard Practice for Mixture Conditioning of Hot Mix Asphalt (HMA)

T 255 Total Evaporable Moisture Content of Aggregates

UDOT MANUAL OF INSTRUCTION PART 8

Section 02746: Hydrated Lime

988.02

Mixing and compaction temperatures must be obtained from the Engineer.

988.03 Apparatus

- **Oven(s) –** Forced-draft, capable of maintaining temperature up to 350°F.
- **Balance or Scale –** Of sufficient capacity and readable to 0.1 g.
- **Thermometer(s) –** Having a range from 120°F to 500°F and readable to 1°F.
- **Mixer –** Of sufficient capacity and design to adequately combine all ingredients.
- **Miscellaneous –** Metal pans, metal spatulas or spoons, timer and gloves, etc.

988.04 Procedure General

Prepare a sufficient number of aggregate samples and quantity of asphalt binder to mix the required number of specimens and have one extra sample for a butter batch.

- Determine masses to the nearest 0.1 g.
- Produce a mixture that contains thoroughly coated aggregate.
- Follow the applicable steps of the procedure listed below for the initial batch to butter the bowl and paddle or whip.
- After buttering, discard the butter batch and scrape bowl and paddle or whip to remove excess material.
- Follow the procedure for each subsequent batch.
- Upon completion of the mixture conditioning, conduct testing or otherwise use the samples for their intended purpose as soon as the required procedures allow.

988.05 Mixing Procedure

1. Heat dry aggregate, asphalt binder, bowl whip and utensils in an oven regulated within the mixing temperature range until temperature has stabilized. Two to four

hours are required for aggregate to reach mixing temperature.

Note: Cover asphalt binder containers. When asphalt binder reaches mixing temperature stir it thoroughly. Asphalt binder may then be stored in an oven at mixing temperature for a short period of time, but must be adequately re-stirred immediately prior to use. Other heating apparatus may be used to maintain asphalt binder temperature provided uniformity in temperature is achieved without localized over-heating. Discard unused asphalt binder after 4 hours of achieving mixing temperature. Do not reheat asphalt binder for subsequent use.

2. Prepare, mix and discard a butter batch.
3. Record mass of buttered bowl and paddle or whip.
4. Remove paddle or whip and zero balance with empty bowl and introduce the aggregate, mix thoroughly
5. Form a crater in the center of the aggregate and determine the aggregate mass.
6. Add sufficient asphalt binder to achieve the desired asphalt binder content expressed as a percent of the total mix. Record the mass of aggregate and asphalt binder actually used for each batch.
7. Thoroughly mix for a minimum of two minutes, or until complete mixing has occurred.
8. Scrape material adhering to paddle or whip into the mixed HMA.
9. Examine the HMA for adequacy of mixing. If any aggregate has not been coated, mix by hand until HMA is properly coated.
10. Remove mix from bowl and scrape bowl, and place all HMA into a baking pan.
11. Record mass of empty bowl and paddle or whip, ensure this mass agrees with the mass of the initial buttered bowl within 0.1% of the sample mass of mixed HMA. .

    Examples:

    4700 g HMA sample, 0.1% = 4.7 grams 2100 g HMA sample, 0.1% = 2.1 grams.

    Immediately subject the HMA samples to the following mixture conditioning procedure.
12. Age according to AASHTO R 30, or other specified test procedure.

988.06 Procedures for Incorporating Hydrated Lime Slurry

Prior to heating aggregate in step 1 of 988.05, add hydrated lime slurry (3:1 water to hydrated lime) to dry aggregate, and mix until uniform (two minutes minimum). For Method A Lime Slurry Induction immediately continue with step 1; ensure aggregate has reached constant mass before mixing with asphalt binder as defined in AASHTO T 255.7.4. For Method B Lime Marination, hold for 24 hours and then continue with step 1. Section 02746: Hydrated Lime

988.07 Procedures for Incorporating Recycled Asphalt Pavement (RAP)

Thirty minutes prior to mixing dry aggregates with asphalt binder, add RAP (at room temperature) to dry aggregate in step 1 of 988.05. Return to oven for remaining 30 minutes. Continue with mixing as above.

Section 960

GUIDELINES FOR SUPERPAVE VOLUMETRIC MIX DESIGN AND VERIFICATION

960.01 Scope

This procedure provides guidelines to determine a Superpave Volumetric Mix Design for Hot-Mix Asphalt (HMA) for incorporation into Department projects. The Contractor will perform and submit the mix design according to specification; the Department will verify the mix design.

REFERENCES:

AASHTO STANDARDS:

M 323 Superpave Volumetric Mix Design

R 30 Standard Practice for Mixture Conditioning of Hot-Mix Asphalt (HMA)

R 35 Standard Practice for Superpave Volumetric Design for Hot Mix Asphalt (HMA)

T 30 Mechanical Analysis of Extracted Aggregate

T 84 Specific Gravity and Absorption of Fine Aggregate

T 85 Specific Gravity and Absorption of Coarse Aggregate

T 166 Bulk Specific Gravity of Compacted Hot-Mix Asphalt Mixtures Using Saturated-Surface Dry Specimens

T 209 Theoretical Maximum Specific Gravity and Density of Hot-Mix Paving Mixtures

T 308 Determining the Asphalt Binder Content of Hot-Mix Asphalt (HMA) by the Ignition Method

T 312 Standard Method for Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

T 319 Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures

TP 62 Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures

UDOT MATERIALS MANUAL OF INSTRUCTION (MOI) PART 8

UDOT MINIMUM SAMPLING AND TESTING REQUIREMENTS

UDOT STANDARD SPECIFICATIONS

UDOT PROJECT SPECIAL PROVISIONS

960.02 Significance and Use

The objective of HMA mix design is to determine the combination of asphalt binder and aggregates that will give long lasting performance as part of the pavement structure. Mix design involves laboratory procedures developed to establish the necessary proportion of materials for use in HMA. Well-designed asphalt mixtures can be expected to serve successfully for many years.

The mix design of HMA is just the starting point to assure that an asphalt concrete pavement will perform as required. Together with proper construction practice, mix design is an important step in achieving well-performing asphalt pavements. In many cases, the cause of poorly-performing pavements has been attributed to poor or inappropriate mix design or to the production of a mixture other than what was designed in the laboratory. To that end, it is critical that the materials and proportions used in the design are representative of the materials and proportions that will be used in the pavement structure.

The purpose of the Mix Design Verification Process is to provide an independent review of the Contractor's mix design. The verification process may consist of any, or all of the following:

- A review of the Contractor's design submittal documentation
- A review of the project history of a previously used HMA design
- A duplication of the Contractor's laboratory effort to verify individual mix components and/or total mix properties.

960.03 Superpave Volumetric Mix Design Guidelines

The mix design shall comply with *AASHTO M 323; Standard Specification for Superpave Volumetric Mix Design* with the following modifications:

Asphalt binder, aggregate and mix properties are defined by project specification, including, but not limited to:

- Dust-to-binder ratio
- VMA
- VFA
- Design air void content (V_a) (% compaction @ N_{des})

- PG asphalt binder grade
- RAP asphalt binder recovered by AASHTO T 319
- Hamburg Wheel-Track Testing (MOI 990) - (replaces Tensile Strength Ratio (Lottman))
- Flakiness Index (MOI 933) – (replaces Flat and Elongated Particles)

The laboratory performing the mix design will be qualified in HMA by the Laboratory Qualification Program. Personnel must be qualified in Transportation Technician Qualification Program (TTQP) Asphalt (AsTT) and Superpave Mix Design (SMD)

The compactor will be approved as per MOI 8-961; Guidelines for Superpave Gyratory Compactor Protocol.

960.04 Standard Practice for Superpave Volumetric Mix Design

Mix Designs will be performed in accordance with *AASHTO R 35: Standard Practice for Superpave Volumetric Design for Hot-Mix Asphalt* with the following modifications:

- Replace G_{sb} with $G_{sb}SSD$ in VMA calculations.

- Target air void content (V_a) is by project specification.

The mix design will be performed using materials intended for use on the project. Materials used in the mix design will meet the following criteria:

- **Asphalt binder** shall be obtained from a certified supplier meeting the requirements outlined in the UDOT *Quality Management Plan 509; Asphalt Binder Management System*. For mix design verifications, the Region Labs will obtain pre-qualified binder from the UDOT Binder Lab.

- **Hydrated lime** shall be obtained from a certified supplier meeting the requirements outlined in *Quality Management Plan 510: Hydrated Lime Management System.* The hydrated lime will be accompanied by test results or will be pre-tested by the Central Materials Laboratory prior to use in the mix design verification.

Requirements when using recycled asphalt pavement (RAP):

- Percentage of RAP in the mix design will be expressed as a percentage of the final mix.

- For mix designs that incorporate more that 15 percent RAP, a test report will be provided for each stockpile of RAP that includes: gradation, aggregate properties, asphalt binder content and PG grade of extracted asphalt binder (AASHTO M 323)

- The final aggregate gradation is determined after the RAP and hydrated lime are added. (AASHTO T 30)

The HMA is mixed according to MOI 8-988. Mixed material will be aged for "Volumetric Mix Designs" as per AASHTO R 30.

After the mix design parameters are determined, prepare and compact four sets of two gyratory specimens. Compact three sets to N_{des} to verify the target air voids, as defined by UDOT Standard Specification 02741, ±0.5% at optimum asphalt binder content. Compact one set to N_{max} to verify required relative density. AASHTO T 312

The Region Materials Laboratory will perform Hamburg Wheel Track Testing of Compacted Bituminous Mixtures (MOI 990). Refer to 960.05 for material submittal.

960.05 Mix Design Verification Process

General:

The Department performs mix design verification; the verification process outlined in this document is intended to be complete. However, verification could include any or all tests identified in AASHTO M 323, project specifications, project special provisions, the current MOI, the current *Minimum Sampling and Testing Requirements* or other aggregate quality, volumetric, or mix performance tests that may be added in the future. All materials submitted for use in the verification process are required to be representative of those used in the mix design.

The Contractor will submit the volumetric mix design data and materials samples for verification at least 10 working days before beginning paving. Paving will not begin until verification is complete. "Working days" refer to Monday through Friday, excluding state holidays, and begin when all the following are submitted to the Region Laboratory:

- Mix Design Report
- *All* aggregate quality test results
- *All* pre-blended aggregate samples
- A *sufficient quantity* of the hydrated lime
- A *sufficient quantity* of the RAP used during the mix design process
- Test Report for RAP
- Test Report for hydrated lime
- Asphalt binder to Central Materials Lab

"Working days" end when the Region Materials Engineer (RME) provides a **Mix Design Review Report** to the Resident Engineer.

960.05.01 Contractor Submittals

Mix Design Report - The Contractor will submit the Mix Design Report to the RME. The Contractor will submit a Mix Design Report Summary and Transmittal Letter to the Resident Engineer (RE). The submittals should follow the outline and example in Appendix "A."

A verified mix design may be submitted for use on a project other than the project originally identified. The Contractor will submit the Verified Mix Design Report to the RME and a Mix Design Report Summary and Transmittal Letter to the RE for the new project. **Both reports must include documentation regarding field changes made after original verification.**

Pre-Blended Samples - The Contractor will prepare samples for use in the verification process. The pre-blended samples, RAP, and hydrated lime are submitted to the RME. The Contractor will provide additional samples upon request.

Note: Asphalt binder for mix design verification will be supplied to the Region Materials Lab from Central Materials Lab.

A pre-blended sample is a blend of the final aggregate structure, without RAP, hydrated lime, and asphalt binder. Pre-blended samples are made at the required sample size by recombining the aggregate portion that has been sieved into individual sieve size fractions. Larger samples split to sample size are not acceptable.

The final gradation of the mix includes the RAP and hydrated lime, as per specification. Mix design verification may include a sieve analysis of the virgin materials and/or of the post-ignition final gradation.

The following tolerances from target gradation for each sieve will be allowed:

1/2 inch	2%
3/8 inch	2%
No. 4	2%
No. 8	1%
No. 16	1%
No. 30	1%
No. 50	1%
No. 100	1%
No. 200	0.8%

Initial pre-blended samples to be submitted:

11 Samples – Gyratory Compaction – AASHTO T 312

5 Samples – G_{mm} Determination – AASHTO T 209

2 Samples – Hamburg Wheel Track Testing – MOI 8-990

- Prepared as above (not mixed)

5 Samples – Dynamic Modulus – AASHTO TP 62

Samples to be submitted after the mix is verified:

4 Asphalt Binder Correction Samples per ignition oven, **AASHTO T 308**
Samples are submitted at mix design binder content and gradation: blend the final aggregate structure with hydrated lime, RAP, and asphalt binder according to MOI 8-988 prior to submitting.

960.05.02 Verification Process

The following information will be evaluated on the submitted Mix Design:

Volumetric Calculations

Air Voids

Asphalt Binder Grade

Gyratory Compaction Effort (N_{values})

VMA

VFA

Aggregate Quality Tests

Hydrated Lime

Gradation:

- The gradation will be evaluated for compliance with the specifications.
- The stockpile gradations and blending percentages must be submitted and may be verified by the Region and compared to the submitted data.

The following tests may be performed on submitted material during the verification procedure. The Region materials laboratory will obtain appropriate asphalt binder for mix design verification from the Central Materials Laboratory. For tests performed on the HMA, the submitted material will be mixed according to MOI 8-988 and aged for "Volumetric Mix Designs" according to AASHTO R 30.

G_{mb} – determined on 3 sets of 2 gyratory specimens compacted to N_{des} – AASHTO T 312 and T 166

%G_{mm} at N_{max} – determined on 1 set of 2 gyratory specimens compacted to N_{max} – AASHTO T 312 and T 166

G_{mm} – AASHTO T 209

Final mix gradation – AASHTO T 30

G_{sb} SSD – fine and coarse aggregate specific gravities – AASHTO T 84 and T 85

Refer to the "Precision and Bias" statement of the AASHTO procedure for acceptable multi-laboratory precision.

Any or all of the quality verification tests may be revisited during production. If any of the aggregate quality tests do not meet the specified criteria, production shall be halted and the issue addressed.

960.05.03 Mix Design Performance Testing

Hamburg Wheel Track Testing of Compacted Bituminous Mixtures MOI 8-990 is a mix design requirement performed by the Region Materials Laboratory after a mix has been verified. The Region Lab will obtain appropriate asphalt binder from the Central Materials Laboratory.

960.05.04 Mix Design Re-Verification:

The RME may choose to approve a previously verified mix design through a review of documentation of the original verification process. The documentation must include results of Hamburg testing. The RME may also require project performance data from use on previous projects.

- The RME may elect to require re-verification of Hamburg Wheel Tracker performance.

The RME will re-evaluate any mix design(s) at any indication of significant changes to the total mix properties and/or any individual component. A complete re-evaluation of HMA mix designs will occur at a minimum of every two years.

960.05.05 Field Mix Design Verification:

The RME may allow a field verification option of the mix design. The Region or Satellite Lab performs the tests for field verification on material placed on an independent test strip outside of the project limits. The verification laboratory is required to perform an ignition oven calibration prior to field mix design verification in order to determine an accurate field asphalt binder content for volumetric calculations.

To verify the mix design, determine that the volumetric properties at N_{des} meet project specifications. The following tests are performed on samples obtained in accordance with MOI 8-984, and reduced in accordance with MOI 8-985.

G_{mb} – determined on a minimum of 3 sets of 2 gyratory specimens compacted to N_{des} – AASHTO T 312 and T 166

$\%G_{mm}$ at N_{max} – determined on a minimum of 1 set of 2 gyratory specimens compacted to N_{max} – AASHTO T 312 and T 166

G_{mm} – AASHTO T 209

% Asphalt Binder Content – AASHTO T 308

Gradation of residual aggregate – AASHTO T 30 – performed on the G_{mm} sample

Hamburg Wheel Track Testing of Compacted Bituminous Mixtures – MOI 990

Should the test results not meet specification the supplier may make adjustments and the process repeated. The mix design is “Not Verified” if test results fail to meet specification after the second attempt.

960.06 Mix Design Review Report

After the verification process is complete, the RME will provide a written summary report to the RE as notification of the results. The Mix Design Review Report will indicate whether the mix design has been:

- **Verified as Submitted**
- **Verified with Conditions**
- **Not Verified**

Results of **“Verified with Conditions”** and **“Not Verified”** will include an explanation of conditions and/or deficiencies.

The Mix Design Review Report will also contain a summary of the region laboratory test results and necessary construction information. Appendix “B” shows an example of information contained in the Mix Design Review Report.

APPENDIX “A”
INFORMATION OUTLINE FOR CONSULTANT / CONTRACTOR
MIX DESIGN REPORT

First Two/Three Pages of Design Submitted Shall Include the Following Mix Design Information:

X Date:

X Laboratory Name:
  Accreditation / Credentials (AMRL/UDOT approved)

X Laboratory Technicians :
  Credentials (UDOT certified)

X UDOT Project Name & Number:

X Nominal Gradation Size:

X Number of Gyrations:
  N_{ini}, N_{des}, N_{max}
  Corresponding ESAL Loading Range

X Gyratory Compactor:
  Brand / Model

X Asphalt Binder:
  PG Grade
  Asphalt binder Source
  Asphalt binder Specific Gravity

X Recycled Asphalt Pavement (RAP) if used:
  Gradation
  PG Grade
  % Asphalt Binder Content
  % Virgin Asphalt Binder used to achieve final asphalt binder content
  % RAP used in mix

X Measured Physical Properties
  Design Mixing Temperature
  Design Compaction Temperature
  % Asphalt Binder Content @ N_{des}
  % Absorbed Asphalt Binder @ N_{des}
  % Effective Asphalt Binder @ N_{des}
  % VMA @ N_{des} (Percent by Weight of Total Mix)
  % VFA @ N_{des}
  % Compaction @ N_{ini}
  % Compaction @ N_{des}
  % Compaction @ N_{max}
  Dust to Asphalt Binder Ratio @ N_{des}
  Maximum Specific Gravity @ N_{des}
  % Hydrated lime Required
  Bulk Specific Gravity G_{sb}
  Maximum Specific Gravity G_{mm}
  Target Gradation

X Proof Testing - (Specification Dependent)
  Hamburg Wheel Tracker

X Aggregate
  One Fracture Face Count
  Two Fracture Face Count
  Fine Aggregate Angularity
  Flakiness

L.A. Wear
Sand Equivalency (Pre-wet Method)
Natural Fines %

X Additional Aggregate Source Information
Sodium Soundness
Unit Weight
Clay Lumps & Friable Particles
Plasticity Index

X Gradation
Stockpile Percentages
Stockpile Specific Gravities & Absorptions
Hydrated lime Specific Gravity & Percentage & Supplier
Target Gradation
Plotted Gradation (0.45 power curve, control points, caution zone)

X Gyratory Design
Calibrated Gyratory Angle
Calibrated Gyratory Pressure
Specimen Heights

Reported Elsewhere in the Submittal:

X Trial Blend
Plotted on 0.45 Power Curve (Control Points, Caution Zone)
Stockpile Percentages
Stockpile Bulk Specific Gravities
Target Gradations
%AC, %G_{mm} @ N_{ini}, %G_{mm} @ N_{des}, %G_{mm} @ N_{max} (Sum.Table)
%AC, % Air Voids, %VMA, %VFA, Dust/Asphalt Binder , %G_{mm} @ N_{ini}, % G_{mm} @ N_{des}, % G_{mm} @ N_{max} (Summary Table @ N_{des})
Trial Blends
AC Percentage
Compaction Results
N_{ini} - N_{des} - N_{max}
Maximum Specific Gravity G_{mm}
Gyratory Equipment Printouts for all Blends
Specimen Heights
Pressure Applied
Gyration Tables for Each Design AC Content
Number of Gyrations
Specimen Height
Estimated Bulk Density
Corrected Bulk Density
% of Maximum Specific Gravity

APPENDIX "B"

Memorandum

UTAH DEPARTMENT OF TRANSPORTATION

DATE:

TO:
Resident Engineer

FROM:
Region Materials Engineer

SUBJECT: Superpave Level I Mix Design Review Report
Project No.:
Project Name:
Contractor:

For the above referenced project, the contractor has indicated that their HMA supplier will be ____, and will be produced at the ______________________ plant.

Nominal Maximum Aggregate Size _________________
Aggregate Source _________________
Asphalt Binder Grade and Brand _________________
Gyratory Compactive Effort
N_{ini} _________________ $\mathbf{N_{des}}$_________________ N_{max} _________________

Based upon a Volumetric Mix Design the following represents the design aggregate structure and optimum asphalt binder content for the required Superpave compactive effort.

The field specimen compaction temperature is ________ and the combined specific gravity (G_{sb}SSD) of aggregates is_______.

Asphalt Binder Grade:_____
Percentage Asphalt Binder:____
RAP percent Asphalt Binder
Virgin % Asphalt Binder
Mixing Temperatures:
Minimum____________
Maximum____________
Minimum Compaction Temperature____________

Stockpile Blends:
____
____
____
____
____

CONTRACTOR'S DESIGN RESULTS:

Hydrated Lime % (Dry Wt. Agg.):

VMA:

Max. Specific Gravity (Rice):

Voids at N_{des}:

Pavement Analyzer Results:

Burn-off Correction Factor:
Field:
Region:

Job Mix Gradation

Sieve	% Passing
1 inch	
3/4 inch	
1/2 inch	
3/8 inch	
No. 4	
No. 8	
No. 16	
No. 30	
No. 50	
No. 100	
No. 200	

Contractor's Superpave Mix Design Was: (See Box Checked Below)

Verified As Submitted **Verified With Conditions** **Not Verified for Following Reasons**

Comments/Conditions/Reasons:____

AASHTO M 323 – STANDARD SPECIFICATION FOR SUPERPAVE VOLUMETRIC MIX DESIGN

1. Which of the following describes binder requirements?
   a. Must be performance graded meeting the requirements of AASHTO M 320.
   b. Must be appropriate for climate and traffic loading of the project for which it is intended.
   c. Must meet the requirements of SP 1 published by the Asphalt Institute.
   d. a & b
   e. All of the above.

2. When RAP (Reclaimed Asphalt Pavement) is used in a Superpave mix design, which of the following best describes what must be done when selecting the virgin binder grade?
   a. Select a binder one grade softer than normal when the RAP percentage is not greater than 15%.
   b. Select a binder one grade stiffer than normal when the RAP percentage is between 15 and 25%.
   c. Select a binder one grade softer than normal when the RAP percentage is greater than 25%.
   d. None of the above.

3. Which of the following are gradation control points or sieves?
   a. Maximum size.
   b. Nominal maximum size.
   c. One sieve smaller than nominal maximum size.
   d. Primary control sieve.
   e. b & c
   f. All of the above.
   g. Who knows?????

AASHTO R 35 – STANDARD PRACTICE FOR SUPERPAVE VOLUMETRIC MIX DESIGN

4. Using the table on the following page, what is the combined percent passing for the No. 4 sieve?
   a. 53
   b. 54
   c. 55
   d. 56
   e. None of the above.

   P = Aa + Bb Cc + . . . Nn

   Where:

   A, B, C …N = Percent passing for individual products (expressed as whole numbers).

   a, b, c, … n = Proportions of individual products used (expressed as decimals).

5. Using the table on the following page, what is the combined G_{sb}(OD) (oven-dry bulk specific gravity) of the blend?
   a. 2.655
   b. 2.657
   c. 2.659
   d. 2.661
   e. None of the above

$$G_{sb}(OD) = \frac{P_1 + P_2 + P_3 + \ldots\ldots\ldots\ldots\ldots\ldots P_n}{\frac{P_1}{G_{sb}(OD)_1} + \frac{P_2}{G_{sb}(OD)_2} + \frac{P_3}{G_{sb}(OD)_3} + \ldots\ldots\ldots \frac{P_n}{G_{sb}(OD)_n}}$$

Aggregate Blending Worksheet

Product Identification	Percentage of Products Used (Decimal)				
	Blend No. 1	**a** (1/2")	**b** (3/8")	**c** (1/4")	**d** (Fine)
A (1/2")	**0.23**	0.23			
B (3/8")	**0.22**		0.22		
C (1/4")	**0.17**			0.17	
D (Fine)	**0.38**				0.38
Total	**1.00**				

Grading for 1/2" (12.5 mm) Mix

Sieve Size	**Comb.**	Individual Product Contributions			
1"	**100**	23	22	17	38
3/4"					
1/2"					
3/8"					
No. 4					
No. 8					
No. 16					
No. 30					
No. 50					
No. 100					
No. 200					

Individual Product Identification and Gradations (Percent Passing)

Sieve Size	**A** (1/2")	**B** (3/8")	**C** (1/4")	**D** (Fine)
1"	100	100	100	100
3/4"	100	100	100	100
1/2"	91	100	100	100
3/8"	12	96	100	100
No. 4	2	20	75	100
No. 8	2	15	21	95
No. 16	2	5	10	78
No. 30	1	2	5	46
No. 50	1	2	3	25
No. 100	1	2	3	18
No. 200	0.3	1.5	2.0	10.3

Combined Specific Gravity and Absorption Data

G_{sb} (OD)					
G_{sb} (SSD)					
G_{sa}					
Absorption					

Individual Aggregate Specific Gravity and Absorption Data

G_{sb} (OD)	2.802	2.641	2.589	2.610
G_{sb} (SSD)	2.810	2.654	2.626	2.635
G_{sa}	2.826	2.676	2.689	2.677
Absorption	0.30	0.45	0.98	0.90

Additional Design Information for Calculation of P_{bi}	
Binder Specific Gravity G_b	1.022
Log S_n (12.5)	1.0969

6. Which of the following is required for calculation of the P_{bi} (initial trial binder content)?
   a. G_{sb}(OD) and G_{sa}
   b. G_{sb}(SSD) and G_{sa}
   c. Estimated G_{se}
   d. a & c
   e. b & c
   f. All of the above.

7. Given the following information, the VMA is _____.
   a. 12.4%
   b. 17.5%
   c. 87.6%
   d. 82.5%
   e. None of the above.

$$VMA = 100 - \left(\frac{G_{mb}\ P_s}{G_{sb(OD)}} \right) \qquad V_a = 100 \times \left[1 - \left(\frac{G_{mb}}{G_{mm}} \right) \right]$$

where:

G_{mm} = 2.479
G_{mb} = 2.335
P_s = 94.3%
$G_{sb(OD)}$ = 2.668

8. Given the above information, the V_a is _____.
   a. 5.8%
   b. 5.9%
   c. 94.2%
   d. 94.3%
   e. None of the above.

9. Given the VMA calculated in question number 7 above, the VMA would be considered appropriate for a 1/2" (12.5mm) Superpave mix design.
   a. True
   b. False

10. During the optimum binder content selection phase of volumetric mix design, five binder contents are used.
    a. True
    b. False

11. Given the following, what is the $\%G_{mm(initial)design}$? Does this meet the Superpave requirements where Design ESALs are 14 million (Yes/No)?
    a. 88.1% - - Yes
    b. 89.9% - - Yes
    c. 88% - - No
    d. 90% - - Yes
    e. None of the above.

$$\%G_{mm(initial)} = 100 \times \left(\frac{G_{mb}\, h_d}{G_{mm}\, h_i} \right)$$

$$\%G_{mm(initial)design} = \%G_{mm(initial)} - \Delta V_a$$

where:
V_a at nearest lower binder content than that resulting in 4.0% = 5.8%
G_{mm} = 2.502
G_{mb} = 2.467
h_d = 116.8 mm
h_i = 130.7 mm

12. Final selection of optimum design binder content is based on compliance with Table 3 ("Superpave HMA Design Requirements") as shown in the FOP for AASHTO R 35. For design ESALs of 7 million, the following meet the requirement.
    a. True
    b. False

Where:

$\%G_{mm}$ @ N_{inial} :	89.8
$\%G_{mm}$ @ N_{design}:	96.0
% G_{mm} @ N_{max}:	98.9
VFA:	68.1%
$P_{0.075}/P_{be}$:	1.4%

AASHTO R 30 MIXTURE CONDITIONING OF HOT-MIX ASPHALT (HMA)

13. Which of the following statements regarding this FOP is correct?
    a. Mixture conditioning procedures for volumetric design and mechanical property testing are the same except for the period of aging (2 hours vs. 4 hours).
    b. Mixture conditioning according to R 30 simulates long-term aging of the mix.
    c. Conditioning in the laboratory is not necessary prior to volumetric mixture testing of plant-produced HMA.
    d. After mixture conditioning of gyratory compaction samples is completed, it is permissible to allow the sample to cool to room temperature temporarily before reheating to compaction temperature.
    e. All of the above.

14. According to this FOP, which of the following statements is **incorrect**?
    a. Prior to laboratory-mixing samples for volumetric testing it is required to first prepare, mix and discard a butter batch.
    b. Mixture conditioning of samples for volumetric mixture design is conducted at mixing temperature for a period of 2 hours ± 5 minutes.
    c. Mixture conditioning for mechanical property testing is conducted at 275˚F for a period of 4 hours ± 5 minutes.
    d. When performing mixture conditioning for mechanical property testing it is required to stir the samples every 60 ± 5 minutes.
    e. All of the above.

15. According to this FOP, when RAP (Reclaimed Asphalt Pavement) is used in volumetric mix design, it must be added to the aggregate for the period required to heat the aggregate to mixing temperature (usually 2 to 4 hours).
    a. True
    b. False

AASHTO T 312 – METHOD FOR PREPARING AND DETERMINING THE DENSITY OF HOT MIX ASPHALT (HMA) BY MEANS OF THE SUPERPAVE GYRATORY COMPACTOR

16. The angle of gyration may refer to either the internal or external angle.
    a. True
    b. False

17. The angle of gyration and pressure applied during compaction must be within a specified range. The correct angle is ________; the correct pressure applied during compaction is ____________.
    a. 1.25±0.02º - - 600±18 Pa.
    b. 1.16±0.02º - - 600±16 kPa.
    c. 1.25±0.02º - - 600±18 kPa.
    d. 1.16±0.02º - - 600±16 Pa.
    e. None of the above.

18. This FOP covers preparing gyratory-compacted specimens that may be used for field control of HMA production processes.
    a. True
    b. False

19. After filling the mold, leveling the HMA and installing the paper disc, what next must be done?

    ____

    ____

    ____

    ____

AASHTO T 283 – RESISTANCE OF COMPACTED BITUMINOUS MIXTURES TO MOISTURE INDUCED DAMAGE

20. Test specimens for T 283 must be compacted to what air void content?
    a. Between 5 and 7 percent.
    b. Between 6 and 8 percent.
    c. Between 6 and 7 percent.
    d. Between 6.5 and 7.5 percent.
    e. None of the above.

21. After saturation it is discovered that the degree of saturation is 65%. What must be done? If the degree of saturation is 81%, what must be done?
    a. For saturation of 65% it is permissible to repeat the saturation process using more vacuum and/or time. For saturation of 81% it is permissible to dry the specimen sufficiently to bring the saturation to within the acceptable 70 to 80% range provided that drying is performed at a temperature of 125 ± 5ºF or lower.
    b. In both cases, the specimen(s) must be discarded because it is never permissible to make further adjustment to specimens outside the range of acceptable saturation.
    c. For saturation of 65% it is permissible to repeat the saturation process using more vacuum and/or time. For saturation of 81% the specimen is damaged and must be discarded.
    d. None of the above.

22. Given the following, calculate the TSR. Does TSR meet Superpave requirements?

$$\text{TSR} = \frac{\text{S2}}{\text{S1}}$$

where:
S1 = unconditioned subset - 133 psi indirect tensile strength
S2 = conditioned subset – 97 psi indirect tensile strength

AASHTO T 324 – HAMBURG WHEEL-TRACK TESTING OF COMPACTED HOT-MIX ASPHALT (HMA)

23. According to this FOP, test specimens for T 324 must be compacted to what air void content?
    a. Between 5 and 7 percent.
    b. Between 6 and 8 percent.
    c. Between 6 and 7 percent.
    d. Between 6.5 and 7.5 percent.
    e. None of the above.

24. Which of the following specimen sizes are appropriate for testing according to this FOP?
    a. Laboratory-compacted slab specimens of 12.5 inch length and 10.25 inch width having thickness of 1.5 inch to 4 inch.
    b. Superpave gyratory compactor specimens having thickness (height) of 1.5 inch to 4 inch.
    c. Wet-cut compacted specimens from HMA pavements. Slabs shall be of approximately 12.5 inch length and 10.25 inch width and thickness of 1.5 inch to 4 inch. Cores shall be 10 inch diameter.
    d. All of the above.

25. Describe how the SIP (stripping inflection point) is determined by using the creep slope and stripping slope.

____

____

____

____

____

____

____

____

AASHTO M 325 – STANDARD SPECIFICATION FOR STONE MATRIX ASPHALT (SMA)

26. Stone Matrix Asphalt (SMA) is an open-graded Hot Mix Asphalt (HMA) mixture with stone-on-stone contact.
    a. True.
    b. False.

27. According to this FOP, which of the following statements is true?
    a. Stone-on-stone contact is defined as the point where the VCA_{DRC} is less than the VCA_{MIX}.
    b. The SMA aggregate specification is based on compliance with all of the Consensus Aggregate Properties, including Sand Equivalent, Coarse Aggregate Angularity (Fractured Face), Fine Aggregate Angularity (Uncompacted Void Content), and Flat & Elongated Particles.
    c. Aggregate quality requirements vary based on design ESAL's and depth from the pavement surface.
    d. Coarse and fine aggregates shall be 100 percent crushed (no natural uncrushed material).
    e. All of the above.
    f. None of the above.

28. According to this FOP, which of the following statements is **incorrect**?
    a. SMA mix design is based on volumetric properties in terms of air voids (V_a), voids in mineral aggregate (VMA), and the presence of stone-on-stone contact.
    b. Binder must comply with AASHTO M 320, and be appropriate for the climate and traffic loading of the project.
    c. Mineral fillers with modified Rigden voids higher than 50 percent should not be used in SMA because such fillers excessively stiffen the SMA mortar.
    d. SMA is a gap-graded HMA mixture consisting of a coarse aggregate skeleton with stone-on-stone contact and a rich asphalt binder mortar.
    e. When the G_{sb}(OD) of the different materials to be used in the mixture vary by more than 0.2, the trial blend grading shall be based on percentage by mass.

AASHTO R 46 – STANDARD PRACTICE FOR DESIGNING STONE MATRIX ASPHALT (SMA)

29. VCA_{DRC} is the volume of voids between coarse aggregate particles in the combined gradation in the dry-rodded condition. VCA_{DRC} is calculated based on the G_{sb}(OD) of the coarse aggregate fraction of the combined grading, G_{mb} of the compacted specimens, and the percentage of coarse aggregate used in the mixture.

    a. True.

    b. False.

30. According to this FOP, which of the following statements is true?

    a. Selection of the optimum aggregate gradation is based in part on the volumetric property results of a minimum of three trial mixtures, compacted using the Superpave Gyratory Compactor (SGC).

    b. When no previous history is available, a starting trial blend binder content between 6.0 and 6.5 percent is required. Trial binder content is selected, in part, based on volume of absorbed binder (V_{ba}), volume of effective binder (V_{be}), and estimated effective specific gravity (G_{se}) of the combined aggregate grading.

    c. Selection of optimum binder content is based on the results of mixtures with four varying binder contents (at P_{b_est}, 0.5% below, 0.5% above, and 1.0% above P_{b_est}).

    d. a & b

    e. b & c

    f. All of the above.

31. Given the following, for Aggregate A, calculate the individual percent retained on the No. 8 sieve. What is the individual volume retained on the No. 8 sieve?

Individual % retained: _____________. Individual volume retained: __________ cm^3.

$$V = \frac{M}{D}$$

Sieve Size	Cumulative % Passing for Product Identification and Percent Usage			
	Aggregate A 35% (a)	Aggregate B 24% (b)	Aggregate C 30% (c)	Mineral Filler (D) 11% (d)
3/4"	100.0	100.0	100.0	100.0
1/2"	65.8	71.2	97.4	100.0
3/8"	42.6	46.4	84.6	100.0
No. 4	9.7	6.3	48.9	100.0
No. 8	4.1	4.1	27.8	100.0
No. 16	2.6	3.1	16.6	100.0
No. 30	2.4	2.9	10.7	100.0
No. 50	2.1	2.6	7.6	100.0
No. 100	1.4	1.8	5.4	89.7
No. 200	1.2	1.7	4.6	72.5
– No. 200				
G_{sb}(OD)	2.536	2.782	2.838	2.425

32. Given the grading information in the table above, what is the individual volume retained for the combined grading on the No. 8 sieve?

__________________ cm^3

$$IVR = (VRA \times a) + (VRB \times b) + (VRC \times c) + ...(VRN \times n)$$

AASHTO T 305 – STANDARD METHOD OF TEST FOR DETERMINING DRAINDOWN CHARACTERISTICS OF UNCOMPACTED ASPHALT MIXTURES

33. Draindown is defined as that portion of the asphalt binder that separates itself from the sample during the test?
    a. True.
    b. False.

34. According to this FOP, which of the following statements is true?
    a. The standard basket is manufactured of 1/4" sieve cloth as specified in AASHTO M 92. The basket has nominal diameter of 4.25 in. with the bottom of the basket elevated above the bottom of the assembly (so material can drain from the basket).
    b. When performing draindown tests during mixture design, two temperatures are selected, plant production temperature and 27 ºF above plant temperature.
    c. If the sample cools more than 45 ºF below the required temperature, the test duration must be increased from 60±5 minutes to 70±5 minutes.
    d. a & b
    e. b & c
    f. All of the above.

35. Using the information below, calculate the reported average drainage.

$$\%\ \text{Draindown} = \frac{M_f - M_i}{M_t} \times 100$$

known:

	Sample 1	Sample 2
Mass of empty basket	2056.8 grams	2063.4 grams
Mass of basket and sample	3287.9 grams	3271.3 grams
Mass of clean plate prior to draindown (M_i)	15.6 grams	15.8 grams
Mass of plate and contents after draindown (M_f)	21.3 grams	19.1 grams

Agency reports drainage to the nearest 0.1%

Average Drainage: ______________________________